THE INCIDENCE AND AVAILABILITY OF LEAD AND STEEL SHOTGUN PELLETS IN DUCKS AND MARSHES IN EASTERN KANSAS

by

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B. S., Michigan State University, 1983

A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Division of Biology

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1986

Approved by:

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ACKNOWLEDGEMENTS

I wish to gratefully thank the many individuals who contributed to the completion of this thesis and my personal and professional development.

My graduate committee, consisting of Drs. Mike Deaton, Ken Kemp, Harold Klaassen, and Fred Oehme helped me through some of the problems with the research, and provided useful critiques of the thesis.

The Kansas City Power and Light Company and the Kansas Fish and Game Commission provided monetary support for the study.

Dr. Mark Guffy and Karen Killough enthusiastically supplied their radiology laboratory and expertise to x-ray the many samples. Dr. Fred Oehme and Rachel Sheeley graciously allowed me the use of their toxicology laboratory and taught me the lead analysis procedure.

To the many hundreds of waterfowl hunters who wanted to get home but voluntarily waited in the check station while gizzards were being removed from their ducks, my many thanks. Without you, the study would not have been possible.

Bill Anderson and the other members of the Patterson Duck Club, and Mike Thiessen and the other members of the Boicourt Shooting Club graciously allowed me access to their property and harvest records. Dr. Spencer Tomb provided interesting and stimulating thoughts during conversations on wetlands, lead vs. steel shot, or waterfowl in general.

Many student assistants provided help collecting both gizzards and soil samples and I enjoyed their company while staying at the study site.

Janice Johnson provided many lighthearted moments around the office, even though she didn't always mean to.

Dan Mulhern played an integral role in this study and was the best of office mates. From orienting me to the campus, to helpful conversation, to collecting field data, he was always there.

My parents, Ron and Roberta Furness, provided me with unfailing support in whatever I wanted to do, and provided encouragement to study wildlife biology in college.

Heartfelt thanks are extended to Rick and Denise Warhurst who generously opened their home to me whenever I was at the study site. I received many delicious meals and a soft bed, and they asked nothing in return. To Rick, I owe my sincerest thanks. He taught me so much about wetlands, waterfowl, and biology in general that I will never be able to repay him. On top of that, he was there helping me collect gizzards and soil samples whenever I needed it.

To Dr. Robert Robel, my major professor, who gave openly of his expertise, opinions, time and funds, I extend deep appreciation and thanks. I especially thank him for allowing me to make mistakes and guide me through them, even though it may have been easier to stop them before they occurred. This was especially true in my writing, and it helped make me a much better scientific writer.

To my daughter Erin, you have brought more joy into my life than I ever could have imagined. Whenever things weren't going well, you were there to take my mind off them and make me laugh. I am sorry for the times I was away from home, and

I promise to make it up to you.

To Norreen, my wife, thank you will never begin to express my feelings. Without you behind me all the way, encouraging me, and being full of understanding, these last few years would have been impossible. You did everything a husband could ever ask of a wife and then some, from helping to collect marsh soil samples while you were pregnant, to typing numerous drafts of this thesis.

INTRODUCTION

Lead poisoning in waterfowl is a well-documented problem. An estimated 2-3% of the North American waterfowl population may die annually due to lead poisoning (Bellrose 1959). Waterfowl deaths from lead poisoning have been recorded since the late 1800's (Phillips and Lincoln 1930). Spent shot is ingested by waterfowl and ground down in the gizzard. The resulting soluble lead is absorbed in the digestive tract causing physiological disturbances of digestive, circulatory, and nervous systems that may ultimately cause death (Bellrose 1976, White and Stendell 1977).

Use of non-toxic steel shot as a substitute for lead shot may be forced by legislation on many areas where lead poisoning of waterfowl has occurred. The United States Fish and Wildlife Service began restricting the use of lead shot in 1976 and attemped to institute a total switch to steel shot in 1980 for portions of 29 states (Wooley 1979). Many state governments and individual hunters resisted this mandatory steel shot requirement. This resistance was aided by the so-called "Stevens Amendment" which has been submitted for inclusion in the Appropriations General Provisions since 1981 by the Department of Interior. This amendement required the U.S. Fish and Wildlife Service to obtain the concurrence of the affected states before implementing and enforcing non-toxic shot zones.

The Kansas Fish and Game Commission decided to implement a non-toxic shot requirement on most of the major public waterfowl hunting areas in Kansas despite the negative feeling by hunters toward steel shot. The Marais des Cygnes Wildlife Management

Area in eastern Kansas is one of the major waterfowl hunting areas in Kansas (Carney et al. 1982). Steel shot was required for waterfowl hunting with 12 gauge guns in 1979 and with all gauges in 1980. The decisions to implement steel shot zones were based on very few data on the incidence of ingested shot in waterfowl or the availability of lead pellets in soil. This 3-year study was begun in 1982 to answer some questions about the lead shot situation around Marais des Cygnes.

Specifically, the objectives of this research were: (1) to determine incidence of ingested steel and lead shot in the most abundant waterfowl species using the Marais des Cygnes Wildlife Management Area and surrounding private hunting club land; (2) to determine the availability of shotgun pellets in the marsh sediments of Marais des Cygnes and two private hunting clubs in the vicinity to feeding waterfowl; and (3) to determine the effectiveness of the non-toxic shot zones at Marais des Cygnes. Very few duck gizzards had been examined for ingested shot in Kansas previous to this study (Carson 1974, Schwilling 1976). The only other study of pellet availability in marsh sediment to ever be conducted in Kansas was a recent study on Cheyenne Bottoms Wildlife Management Area in central Kansas (Brungardt 1985). Incidence of ingested shot in waterfowl gizzards is taking on added importance because the U.S. Fish and Wildlife Service has recently proposed using incidences of ingested shot as criteria for establishing non-toxic shot zones.

LITERATURE REVIEW

History of the Lead Poisoning Problem

Lead poisoning of waterfowl and its solution have plagued biologists for almost a century, and the topic has generated literally thousands of pages of research papers. Still, the problem persists today and has sparked numerous arguments, often pitting one interest group against the other.

Lead shotgun pellets are deposited on the bottoms of wetlands across North America by waterfowl hunters. As much as 2.7 million kg of spent pellets are deposited in lakes and marshes in the United States annually [United States Fish and Wildlife Service (USFWS) 1976]. Spent lead shot, though not a major source of particulate lead in the environment, generally is the primary source of lead in waterfowl tissues (USFWS 1976). The subsequent poisoning due to this is one of many mortality factors in wild waterfowl (Finley et al. 1976). Not all lead pellets that fall in wetlands are available to waterfowl. Physical factors, such as soil type and corresponding bottom firmness, amount of sedimentation, wave action, water depth, and ice cover all affect pellet availability (Wills and Glasgow 1964, USFWS 1976).

One of the first articles published about waterfowl lead poisoning appeared before the turn of the century (Grinnel 1894). Two more articles also appeared in the same publication that year about lead poisoning (Anonymous 1894a,b). Little was written about waterfowl lead poisoning for the next decade. Bowles (1908) described a number of mallards (*Anas platyrhynchos*)

either sick or dead on the "Misqually Flats" in Puget Sound, Washington. The dead birds contained greater than 19 lead pellets each, and the author asked if such acondition had ever been reported before. McAtee (1908) answered him in the next issue, and reported that conditions similar to those existed each year in canvasbacks (Aythya valisineria) on Lake Surprise, Texas. McAtee (1908) predicted that these lead poisoning outbreaks would in all probability increase in number in the future, adding another unfavorable condition against which ducks must struggle. Wetmore (1919) was one of the first to conduct research concerning lead poisoning in waterfowl. He described the symptoms and effects of lead poisoning, experimentally dosed ducks with lead pellets, and investigated the amount of shot in sediments near hunting blinds.

Bellrose (1959) gave accounts of 42 lead poisoning die-offs of waterfowl numbering from 40 to 16,000 between the years 1938 and 1957 nationwide. He also uncovered reports of nine die-offs prior to 1937, relying mostly on unpublished accounts.

Since 1960 there have been published reports of large die-offs due to lead poisoning almost annually (Table 1). Many involved either Canada geese (Branta canadensis) or mallards. The only published report of a lead poisoning die-off in Kansas was in Bellrose (1959), where he reported a loss of 200-250 mallards in 1953 on Reeves Lake in Grant County, in the extreme southwestern corner of the state. However, a letter from B. King, then manager of the Marais des Cygnes Wildlife Management Area, to the Chief of the Game Division of the Kansas Fish and Game

Table 1. Die-offs of waterfowl due to lead poisoning reported in the literature since 1960.

Species affected	Year	Number dead	State	Source
Canada geese	1962 and '63	600	WI	Trainer and Hunt 1965
Mallard	1963,'65,'77, '78, and '79	8,000	MO	Humburg and Babcock 1982
Mallard and Pintail	1964	2,000	LA	Wills and Glasgow 1964
Ducks in general	1967	1,000	KS	Files, Marais des Cygnes WMA[a]
Lesser scaup	1972	1,500	IL	Anderson 1975
Snow geese	1973	2,000	LA	West and Newsom 1979
Canada geese	1974	925	CO	Szymczak and Adrian 1978
Canada geese	1977 and '79	3,700	IL	Anderson and Sanderson 1979
Ducks in general	1980	1,000	SD	Fowler 1981
Canada geese	1980	3,600	SD	Fowler 1981
Canada geese	1981	3,700	WI	Wooley 1981
Canvasback	1981	400	IL	Anderson 1982a
Mallard	1981	150	IL	Anderson 1982b

[a]Not reported in the literature

Commission dated 23 February 1967, states that the Area had a kill of waterfowl due to lead poisoning in 1961 and 1967. An estimated 1,000 ducks died in 1967, but considerably less died in 1961 (Files, Marais des Cygnes Wildlife Management Area).

Waterfowl die-offs due to lead poisoning are usually preceded by ducks ingesting spent lead shotgun pellets. Waterfowl feeding in heavily hunted areas ingest lead pellets in wetlands and in upland fields (Humburg and Babcock 1982). The birds either pick up pellets intentionally, mistaking them for food or grit, or unintentionally while feeding (USFWS 1976).

Individual waterfowl species are not equally susceptible to lead poisoning. Food preferences and feeding habits are the major factors controlling whether a species is prone to lead poisoning or not (Bellrose 1959). A grain diet, especially corn (Zea mays), appears to be a major contributor to lead poisoning in waterfowl. A more varied diet which includes green vegetation often reduces toxic effects of lead (Jordan and Bellrose 1950, Irby et al. 1967, Humburg and Babcock 1982). Studies by Longcore et al. (1974) showed that the presence or absence of grit in the gizzard and type of grit affected toxicity of ingested lead shot. In ducks with grit, the result was less, but more rapid, mortality than ducks without grit. Species whose feeding habits include sifting and digging into the bottom soil where pellets are present have a much higher chance of ingesting pellets than those who feed on the mud surface or on aquatic plants.

Bellrose (1959) in a survey involving over 36,000 duck and goose gizzards, found that the species with the lowest rates of

lead shot ingestion (less than 2%) were shovelers (Anas clypeata), green-winged teal (A. crecca), gadwalls (A. strepera), wood ducks (Aix sponsa), mergansers (Mergus spp.), and buffleheads (Bucephala clangula). These species either feed on the surface of the mud bottom (shoveler, teal), on vegetative parts of aquatic plants (gadwall), on fruits in flooded woodlands (wood duck), on fish (merganser), or on animal life in open bodies of water (bufflehead). Mallards and pintails had ingested shot incidences of between 7 and 9%, and actively sift through mud in heavily shot-over areas searching for seeds. Redheads (Aythya americana), ring-necked ducks (A. collaris), canvasbacks, and lesser scaup (A. affinis) all exhibited shot ingestion rates over 11%. The latter four species normally dive for food in comparatively shallow water in their search for seeds, tubers, and rootstocks of aquatic plants (Bellrose 1959).

Mallards show the greatest mortality rate of any duck species after a lead pellet has been ingested, with pintails having the next greatest mortality (Bellrose 1959). Wigeon (Anas americana), which had a 3% shot ingestion rate, have a negligible lead poisoning mortality rate due to its aforementioned beneficial leafy aquatic vegetation diet. Redhead, ring-necked duck, canvasback, and lesser scaup lead poisoning die-offs are rare because they all have vegetative diets (Bellrose 1959). Other factors which determine individual susceptibility to lead poisoning are the number of lead pellets ingested, environmental stresses such as weather, and physiological condition of the bird (Humburg and Babcock 1982).

Numerous other investigators have documented incidence of shot ingestion in all parts of the country. While absolute percentages differ from location to location, the relative positions of species from a low to a high ingested shot incidence stays somewhat constant. Green-winged teal, blue-winged teal (Anas discors), wigeons, gadwalls, and wood ducks consistently have ingestion rates less than 1.5% (Longcore et al. 1982, Moser and Keeler 1982). The mallard is the best species to use to compare shot ingestion rates over large geographic areas because it is so ubiquitous. Previous mallard ingested shot incidences found invarious states are as follows: Maine 3.0% (Longcore et al. 1928); New York 11.6% (Moser and Keller 1982); Illinois 6.5% (Welch 1976); Illinois 9.7% (Anderson and Brewer 1980); Illinois 5.2% (Anderson 1982a);Kansas 3.8% (Carson 1974); Kansas 4.0% (Schwilling 1976); and Missouri 6.0% (Humburg and Babcock 1982).

Incidence of ingested shot in all duck species studied was found to be lowest in the Central Flyway, with a rate of 3.1%. The incidence of shot was higher in the Atlantic Flyway (6.3%), somewhat higherin the Pacific Flyway (6.8%), and highest in the Mississippi Flyway (8.6%) (Bellrose 1959). The samples used in these figures were not randomly selected, and even though more recent surveys may have been more widely distributed, there still were seasonal and geographical biases. However, the geographical pattern of incidence of ingested shot has remained similar through the years (USFWS 1976). Bellrose (1959) estimated a 2-3% annualloss of the continental waterfowl population due

to lead poisoning. In recent years estimates of the autumn duck population of North America range from a low of 62 million in 1985 to a high of 100 million in 1972 (Anonymous 1985b).

It is generally believed that hunting accounts for 50% of the annual mortality of waterfowl (Bellrose 1976, USFWS 1976, Humburg et al. 1982). An estimated annual North American duck harvest of 12.5 million occurred between 1981 and 1983 (USFWS 1982, 1983, 1984). Nonhunting mortality - disease, predation, and accidents - accounts for the remaining 50%, or 10-20 million ducks and geese. Disease directly or indirectly accounts for the largest proportion of nonhunting deaths (Bellrose 1976, Stout and Cornwell 1976, Humburg et al. 1982). Stout and Cornwell (1976) compiled information concerning nonhunting losses of more than 2 million waterfowl. Diseases and poisons were responsible for 87.7% of total losses followed by mortality due to weather (7.4%), miscellaneous (3.7%), pollution (0.6%), predation (0.1%), and collisions (0.1%). Lead poisoning losses of 1.5 to 2 million ducks annually are only part of the overall nonhunting mortality. Other diseases causing extensive waterfowl mortality include duck plague (Duck Virus Enteritis), fowl cholera, aspergillosis, and botulism (Hayes and Davidson 1978). Of all diseases that affect waterfowl in North America, none has caused more massive or visible losses than botulism (Bellrose 1976, Hayes and Davidson 1978). In 1952 an estimated 4 to 5 million waterfowl died of botulism (Hayes and Davidson 1978). Few figures are available showing annual percentages of waterfowl lost to each of the major diseases, except for the 2-3% annual loss figure reported

for lead poisoning. However, together the annual loss percentages total 10-20% of the North American waterfowl population.

Bird species other than ducks and geese also have been reported to ingest shot, although at a greatly reduced frequency. Jones (1939) described lead poisoning mortality of sora rails (Porzana carolina) discovered by another worker in North Carolina where dozens of dead and dying birds were found around heavily hunted rice fields. Jones (1939) in another survey found that 23 to 334 sora rails examined contained ingested shot. Artmann and Martin (1975) found ingested shot in 12.3% of a sample of 767 sora rails collected in Maryland. Other aquatic species reported to ingest lead shot include the American coot (Fulica americana), king rail (Rallus elegans), clapper rail (R. longirostris), and Virginia rail (R. limicola) (Jones 1939). Mourning doves (Zenaidura macroura) ingest shot while feeding in intensively managed dove hunting fields. Lewis and Legler (1968) examined gizzards from 1,949 doves and found that 1.1% of the gizzards contained shot. Another sample of 62 doves contained 4 with ingested shot (Locke and Bagley 1967).

Raptors are also susceptible to lead poisoning. Most of the lead poisoning cases among wild free-ranging raptors involved bald eagles (Haliaeetus leucocephalus) (Jacobson et al. 1977, Redig et al. 1980, Feierabend and Myers 1984, Anonymous 1985a). Bald eagles seem vulnerable because they readily consume dead or crippled prey which may contain lead shot or tissue-bound lead, and are closely associated with the same wetland complexes frequented by waterfowl (Griffin et al. 1982, Pattee and Hennes

1983). At least 36 bald eagles have died of lead poisoning since 1980, 10 of which have died since September 1983 (Feierabend and Myers 1984). Eighty-three bald eagles have been documented to have died from lead poisoning in the last 20 years (Anonymous 1985a). In fact, lead poisoning ranks fourth behind shooting, electrocution, and impact injuries as the leading cause of death among bald eagles (Kaiser et al. 1980, Anonymous 1985a).

Metabolic Absorption of Lead

Absorption of inorganic compounds depends heavily on the compounds' solubility. Metals coming in contact with the body in elemental form are usually poorly absorbed. However, finely powdered metals are more soluble than large pieces of the same compound, and ingestion of metals by animals with highly acidic digestive tracts provides increased opportunity for absorption (Oehme 1978).

Lead shotgun pellets are subjected to severe grinding action by the gizzard and chemical action by the gastric juices (Humburg and Babcock 1982). The gastric juice in the gizzard is a solution of hydrochloric acid and enzymes. The pH varies from 2.0 to 3.5 and the major enzyme is pepsin (Kimball and Munir 1971).

The lead is broken down in the gizzard into lead salts, which are insoluble in water. These lead salts are dissolved readily by the gastric juices and absorbed from the small intestine to the bloodstream by diffusion. Following absorption, lead is rapidly removed from the plasma to combine with the blood cellular elements. Nearly all of the ciculating inorganic lead is

associated with the erythrocytes, chiefly in the membrane stroma (Oehme 1978).

The direct effect of one dietary component on the assimilation of another plays an important role in individual variation of lead solubility, absorption, and deposition (Shields and Mitchell 1941). Shields and Mitchell (1941) state that concentrations of calcium and/or phosphorous above certain limits appears to impair absorption of dietary lead. The influence of calcium and phosphorous on lead deposition is well documented (Tompsett 1939, Shields and Mitchell 1941, Sobel et al. 1949). These authors have shown that lead storage is increased by a low-calcium diet and decreased by a high-calcium diet.

Effects of Lead Poisoning on Waterfowl

Virtually all of the body systems to which the absorbed lead is distributed are adversely affected, particularly the digestive, nervous, and circulatory systems (Cook and Trainer 1966, March et al. 1976, White and Stendell 1977, Dieter and Finley 1978). The basis of the toxic action of lead is that it blocks the sulfur-hydrogen linkage in enzymes, thereby disrupting their action. This results in a reduction in glycolysis and a reduction of oxygen consumption by all tissues. Lead, at physiologically low concentrations, interferes with the production of hemoglobin by inhibiting the enzymes necessary for the production of heme. As a result, anemia may occur (Bates et al. 1968).

The effects of lead on the liver include atrophy, necrosis of liver cells, and considerable hemosiderosis (Locke et al. 1967,

Grandy et al. 1968). In waterfowl kidneys, lead caused acid-fast intranuclear bodies in the cells of the proximal convoluted tubules to be formed and destroyed kidney tubular cells (Locke et al. 1967).

Hunter and Wobeser (1979) found the primary effects of lead on the central nervous system to be within the cerebellum, and felt that the peripheral nervous system may be more vulnerable to lead than the central nervous system. Peripheral nervous tissue is damaged early in lead-poisoned ducks, and precedes anemia. Nervous tissue damage may be important in producing the clinical signs of lead poisoning (Hunter and Wobeser 1979).

The typical clinical signs of lead poisoning in waterfowl have been discussed by many workers (Wetmore 1919, Adler 1944, Coburn et al. 1951, Trainer and Hunt 1965, Cook andTrainer 1966, Locke et al. 1967). Some of these clinical signs include emaciation, reduced activity with reluctance tofly, lowered food intake, wing droop, green bile staining of vent area, and loss of ability to walk or stand. Pathologic findings include lack of fat, atrophy of striated muscle, liver, and kidneys, distended spleen and gall bladder, atrophied and bile staind gizzard, and an impact proventriculus. Waterfowl with acute lead poisoning usually are dead within 5-20 days (Cook and Trainer 1966; Irby et al. 1967, Grandy et al. 1968).

The chronic effects of lead shot ingestion, however, are poorly understood. Lead poisoning can predispose waterfowl to other infectious agents, thereby contributing to disease losses that may not be directly attributable to lead poisoning per se (Hayes and Davidson 1978). Chemicals such as lead, in amounts too small to be noticeably toxic, can nevertheless interfere

with well-established host-parasite relationships and result in clinical disease. Lead poisoning may stress Canada geese enough for aspergillosis to develop, and the infected birds may then infect others in the flock (Friend 1975). Laboratory analysis of a die-off of snow and blue geese in northeastern South Dakota in 1975 confirmed field observations that both lead poisoning and avian cholera were principal causes of the mortality. The high percentage of lead poisoned birds in the sample suggested that lead may have been the "stress factor" that caused the avian cholera outbreak (Friend 1976).

The added stress alone could cause an increased susceptibility to predation or mortality due to hunting. Bellrose (1959) showed in a field experiment that ducks afflicted with lead poisoning during the hunting season are more likely to be bagged than healthy birds. Wild mallards that were dosed with one No. 6 lead shot pellet each and released were 1.5 times as vulnerable to hunting as controls, and those dosed with two pellets each were almost twice as vulnerable as the controls.

Lead pellet ingestion may or may not affect egg fertility or hatchability (Cheatum and Benson 1945, Elder 1954). Cheatum and Benson (1945:29) summarized what they considered to be the obvious effect of lead on reproduction when they stated that "It seems certain that breeding activity would be reduced to a minimum in view of the obvious reduction in vitality of poisoned waterfowl during periods of lead absorption and convalescence." However, the chronic effects of lead poisoning have received very little study, and certainly merits future research (Friend 1975, Friend

1976, Hayes and Davidson 1978).

It is even more of a problem to document low-level, day to day losses of waterfowl due to chronic cases of lead poisoning. Economic, time, and manpower limitations make it impractical to search entire wetland areas on a daily basis to provide estimates of total losses, and only a portion of actual losses are found through periodic sampling. Scavenging activity by raptors and mammalian predators is one of the most important factors precluding documentation of total losses. Nearly one-half of the intact carcasses observed to study scavenging rates at Squaw Creek, Missouri, were gone after four days (Humburg et al. 1982). A similar study in Texas found that 50% of all carcasses placed in overhead cover disappeared in one day (Stutzenbaker et al. 1983).

The other important factor making chronic losses difficult to document is the fact that it is hard to even find birds that are there. In the same Texas study, 100 carcasses were deposited in a 40.5 ha tract of marsh. Fifty of the birds were placed in typical escape cover and 50 were randomly placed in completely exposed positions on top of vegetation. An 8-man search crew, which was unaware that the birds had been deposited 30 minutes earlier, was sent to look for dead birds. The searchers found none of the carcasses placed in escape cover and only 6 of the 50 placed on top of vegetation (Stutzenbaker et al. 1983).

Methods Used to Document Lead Ingestion and/or Lead Poisoning

Physical and chemical methods are used to document waterfowl exposure to lead. Physical methods show that a potential exists

for poisoning to occur, and chemical methods determine if a certain individual has been lead poisoned. The first physical method consists of cutting open the gizzard and manually searching for shotgun pellets. This is the most commonly used method to show waterfowl exposure to lead shot. Representative studies using this method include those by Bellrose (1959), Anderson (1975), Welch (1976), Trost (1980), Wooley (1981), and Anderson and Havera (1985). Visual examination of gizzard contents is time consuming, and also can be inaccurate. Both Montalbano and Hines (1978) and Anderson and Brewer (1980) found that manual examination of gizzard contents may miss up to 25% of the pellets present. Flouroscopy and radiology are the other physical methods. Flouroscopy was the earlier methodology and was used on whole gizzards or dead or alive whole ducks (Bellrose 1959, USFWS 1976). However, Montalbano and Hines (1978) found that flouroscopy gave a poor resolution of the image and that 28% of the pellets present in a sample were missed. Radiologic examination of gizzard contents followed by manual examination of the contents that produced a positive signature on the radiograph is now considered to be the most accurate method of determining incidences of ingested shot (Montalbano and Hines 1978, Anderson and Brewer 1980, Anderson and Havera 1985).

Chemical methods to detect lead poisoning focus on analyzing lead content of major organs, blood, or bone. Lead is stored in bones of waterfowl and may be present in varying amounts depending on several factors. Continous low-level oral doses of lead over a long period of time may result in the highest levels in bones,

lower levels in liver and kidney, and lowest levels in heart, lung, muscle, and brain. High levels of lead in liver and kidney are indicitive of recent high exposure to lead (USFWS 1976).

Lead levels in liver tissue are the most reliable for diagnosing acute lead toxicosis (Adler 1944, Coburn et al. 1951, Cook and Trainer 1966, Longcore et al. 1974). The early method of determining lead content was the colorimetric dithizone method described in Methods of Analysis of the Association of Official Agricultural Chemists (Anonymous 1940). More recently, atomic absorption spectrophotometry has been the method most often used (Longcore et al. 1974, Anderson 1975, Finley et al. 1976, Szymczak and Adrian 1978, Scanlon et al. 1980, Calle et al. 1982).

Wet weight is a popular basis for reporting heavy metal toxicity in soft tissues (Longcore et al. 1982). However, Adrian and Stevens (1979) report that sizeable errors are possible because of the analyst's inability to achieve consistency in the wetness of the tissue. Adrian and Stevens (1979) recommend using dry weight when making heavy metal determinations. Wet weight has been used almost universally lead poisoning field, however. Lead levels that range between 6 and 20 ppm (wet weight) in the liver are considered an indication of recent, acute lead exposure and as being diagnostic of active lead intoxication (Longcore et al. 1974). Background levels of lead averaged 0.5 to 1.5 ppm (wet weight) in the livers of 11 different species of waterfowl with no known history of lead exposure (Bagley and Locke 1967).

The liver is not the only organ that is analyzed to determine lead toxicity. The kidney, heart, lung, spleen, and pancreas have

also been used (Adler 1944, Longcore et al. 1974, Anderson 1975). However, the liver is the one most often used (Longcore et al. 1974).

Determination of levels of lead in blood and concentration of blood protoporphyrin also are methods used to measure lead levels (Roscoe et al. 1979, Anderson 1982a, Anderson and Havera 1985). A 1-2 ml blood sample is taken from each live-captured duck to analyze for lead levels and the duck can then be released (Anderson 1982a). Atomic absorption spectrophotometry can then be used to analyze the blood for lead content (Longcore et al. 1974, Szymczak and Adrian 1978, Anderson 1982a, Anderson and Havera 1985). Protoporphyrin, a pigment in blood and a precursor to hemoglobin, increases as a specific response to lead poisoning in ducks and geese (Roscoe et al. 1979). A hematoflourometer is used to analyze blood protoporphyrin, and it is an accurate and inexpensive method for diagnosing lead toxicosis in waterfowl (Roscoe et al. 1979). The minimum levels for a diagnosis of lead toxicosis in waterfowl are 0.50 ppm of lead in blood and 40ug/dl of protoporphyrin (Roscoe et al. 1979).

Bone is another tissue analyzed using atomic absorption spectrophotometry to determine lead exposure (Longcore et al. 1974, Anderson 1975, Stendell et al. 1979). Bone is a storage site for lead, and residues in bone can either indicate the animal's exposure to this element in the immediate past or over a long period of time. Uptake of lead by bone is rapid, and loss is slow. Residues in bone reflect both acute and chronic exposure to lead from all sources including the atmosphere and automobile

exhaust (Stendell et al. 1979). The use of bone lead levels as a suitable criterion for determining acute lead poisoning is questionable, but its presence is evidence of exposure to lead (Longcore et al. 1974).

Shot in Sediments

Numerous accounts of amount of shot present in marsh sediment and upland soil can be found throughout the litersture. Anderson (1982b) states that the threshhold level of number of pellets that must be present to constitute a lead poisoning hazard to wildlife appears to be about 50,000/ha. Bellrose (1959) listed amounts of shot in sediment from 24 areas across the country, with the highest amount of shot being 291,600/ha on Lake Puckaway, Wisconsin (Hartmeister and Hansen 1949). Most of the pellet densities were under 123,500. Jessen and Lound (1959) reported a shot density of 109,700/ha from heavily hunted areas in Minnesota, and Esslinger and Klimstra (1983) found a similar density in Union County Conservation Area in Illinois. However, Wooley (1979) researching the Illinois area found only 19,700 pellets/ha. In a hunting area with a high siltation rate on the Upper Mississippi National Wildlife Refuge, a density of 2,400 pellets/ha was found (Trost 1980). Schrank and Dollahon (1975) reported a pellet density of 99,000/ha in a small New Mexico impoundment hunted for 5 years. A similar shot density was found in sediments in Merrymeeting Bay, Maine, even though this area is subjected to wave and tidal action (Longcore et al. 1982). A pellet density of 74,000/ha was reported from random samples on

50,000 ha Catahoula Lake in Louisiana (Wills and Glasgow 1964). Anderson (1982b) found an average pellet density of 93,600/ha on Rend Lake in Illinois, with one plot yielding 187,200 pellets/ha. Frederickson et al. (1977) sampled a wildlife area in Missouri around permanent hunting blinds before and after cultivation, and found shot densities of 303,400/ha and 64,500/ha, respectively. In a study done in Kansas, Brungardt (1985) reported a range of 82,000-247,000 pellets/ha around 20-year old hunting blinds on Cheyenne Bottoms Wildlife Area. Studies were conducted at two wetland waterfowl hunting areas in Missouri in the late 1970's and pellet densities around two hunting blinds were 493,000 pellets/ha and 396,900 pellets/ha (Humburg and Babcock 1982). Areas of high pellet concentration were also recorded at Oakwood Bottoms Greentree Reservoir, where specific sites yielded from 186,000 to 438,000 pellets/ha (Hansen 1976).

Wetlands are not the only areas where lead shot accumulates. Lewis and Legler (1968) sampled a dove hunting field in Tennessee before hunting season and found 26,898 pellets/ha. Immediately following a 2-day hunt the field was resampled by the same authors and they found 107,600 pellets/ha. A put-and-take pheasant hunting area in Illinois had a pellet density of 136,000/ha (Anderson 1983).

Three major methods have been used to document number of pellets present in marsh substrate or upland soil, depending on water depth, vegetation present, and firmness of the soil or substrate. An Ekman dredge is commonly used in areas of soft bottom sediments and little vegetation present (Jessen and Lound

1959, Trost 1979, Longcore et al. 1982). Core samplers various sizes in diameter are used in flooded and/or vegetated wetlands, as long as substrates do not consist of gravel (Wills and Glasgow 1964, Wycoff et al. 1971, Brungardt 1985). Most authors have depressed a square angle iron frame into dry or moist soil and collected the soil inside the frame outline (Lewis and Legler 1968, Schrank and Dollahon 1975, Frederickson et al. 1977, Wooley 1979, Anderson 1982b, Anderson 1983, Esslinger and Klimstra 1983).

Once samples are collected, they are usually analyzed using one of two methods. The first involves sieving the sample and manually searching through the remaining material to locate pellets (Lewis and Legler 1968, Schrank and Dollahon 1975, Federickson et al. 1977, Wooley 1979, Longcore et al. 1982, Esslinger and Klimstra 1983). A more recent method involves using radiography to locate pellets in soil samples. The samples may be sieved first or they can be x-rayed whole (Anderson 1982b, 1983, Fisher in press).

Low and Studinsky (1967) and Wycoff et al. (1971) used various lead shot sizes to compare shot settling rates. Both studies showed no difference in settling rate as related to shot size. Bellrose (1959) compared settling rates of pellets in two bottom types. Most of the shot in the soft bottom soil had settled to the 2.5-5.0 cm layer after one year. However, in moderately firm bottom soil, the bulk of the shot was in the top 2.5 cm layer.

Based on this literature review it was obvious that much research has been done on waterfowl lead poisoning. However it

became clear that a paucity of information existed about the extent of the lead poisoning problem or even the potential for problems in Kansas. This study was designed to fill in this gap in the literature.

STUDY AREAS

General Description

One state-owned wildlife area and two nearby hunting clubs in eastern Kansas were chosen for study in this research. The Marais des Cygnes Wildlife Management Area (MDCWMA) is located in Linn County and is controlled by the Kansas Fish and Game Commission. The Boicourt Shooting Club lies between disjunct units of the MDCWMA on 77.5 ha Boicourt Lake. The Patterson Duck Club is situated 2.5 km northeast of the MDCWMA (Fig. 1). The MDCWMA is located approximately 100 km south of Kansas City and 5 km west of the Kansas-Missouri state line. The Kansas towns of LaCygne and Pleasanton lie approximately 5 km to the north and south of the MDCWMA, respectively (Fig. 2).

Ducks using this complex of wetlands for feeding and resting during migration can be considered as one population. Parr et al. (1979) reported that wood ducks will travel up to 10 km daily from roost site to feeding areas. Baldasarre and Bolen (1984) stated that flocks of northern pintails, green-winged teal, American wigeon, and mallards wintering in Texas rarely exceed flights of 5 km from playa lakes to cornfields, with 15 km the longest flight observed. The distance from the south end of the MDCWMA to the north side of the Patterson Club is 9.7 km, and the east-west distance of the MDCWMA is 6.4 km.

The three sites are located either on the floodplain of the Marais des Cygnes River or one of its tributaries. Several tributaries enter the Marais des Cygnes River within the boundaries of the MDCWMA. Middle Creek and North Sugar Creek enter from the

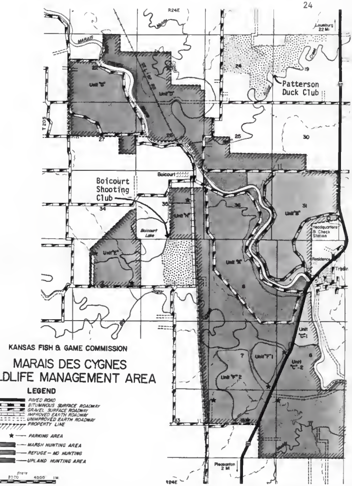

Fig. 1. Map of the Marais des Cygnes Wildlife Management Area and locations of the Boicourt Shooting Club and Patterson Duck Club.

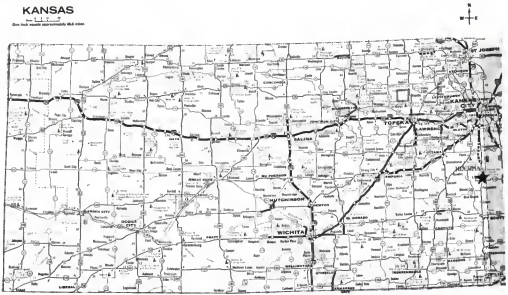

Fig. 2. Location of the Marais des Cygnes Wildlife Management Area in eastern Kansas.

north, Big Sugar Creek enters from the west, and Muddy Creek from the south (Fig. 1).

The Marais des Cygnes River valley through the area is characteristic of a mature stream with a wide fertile floodplain. Natural freshwater marshes,oxbow lakes, floodplain forest, oak-hickory upland forest, and bluestem prairie areas were all original components of the local environment. The banks of the river have built up over many years of past floodings. In some places this has resulted in a natural dike which is as much as 1.8 m higher than the swampy land in the floodplain away from the river (Gasswint 1981). Between 1928 and 1948 the river overflowed its banks 34 times. During 1951 the river was above bankfull for 38 days. The river has been out of its banks an average of two times in each of the last 10 years (Geiger et al. 1983).

The average discharge for the past 24 years of the Marais des Cygnes River measured at the point it leaves state-owned land was 55.6 m^3/sec. For water year 1982 (October 1981-September 1982) the mean discharge was 89.8 m^3/sec, with a maximum of 612 m^3/sec and a minimum of 0.6 m^3/sec. Maximum flows (and floods) normally occur in the months of May and June, with minimum flows in August, September, and October (Geiger et al. 1983).

The topography of Linn County is a slightly dissected plain, which is interrupted by a series of low ridges with southeast-facing escarpments. The elevation ranges from 237.7 to 350.5 m above sea level. The soils are moderately deep, and have a silty and clayey subsoil (Penner 1981). Osage silty clay is the overwhelmingly predominant soil type on the floodplains and in

the marshes on the study sites. This soil is deep, nearly level, and poorly drained. Permeability is very slow, as is surface runoff. Typically, the surface soil is black silty clay approximately 58.4 cm thick. The upper part of the subsoil is very dark gray, mottled, very firm silty clay. The substratum to a depth of 152.4 cm is gray, mottled clay (Penner 1981).

Linn County has a continental climate characterized by large daily and annual variations in temperature. The average annual daily temperature is 13.6°C, with a range between 26.3°C in July and -0.4°C in January. Typically, the first frost comes before 23 October, and the last frost occurs later than 13 April (Penner 1981). Marshes are generally frozen during late December, January, and early to mid-February (R.A. Warhurst, pers. commun.).

The average annual precipitation in the county is 97.9 cm, with 50% of it occurring in May, June, August, and September as late-evening or nighttime thunderstorms. Seasonal snowfall averages 44.5 cm, and at least 2.5 cm of snow is on the ground an average of 20 days. December and January each average approximately 12.7 cm of snowfall (Penner 1981). Snow up to 5 cm deep does not discourage mallards from feeding in cropfields. However, snow more than 10 cm deep discourages most cornfield-feeding by mallards (Madson 1964). The light amount of snowfall in Linn County many years allows mallards to feed in fields throughout the entire winter.

Cropland accounts for 43% of the land use in the county, followed by pastureland (33%), woodland (11%), rangeland (10%), and urban uses (3%). Of the amount of land used for crops in the

period 1967-1977, 28% was used for soybeans (Glycine max); 25% for sorghum (Sorghum bicolor); 20% for corn; 17% for wheat (Triticum aestivum); and the remaining 10% for alfalfa (Medicago sativa), oats (Avena sativa), rye (Secale cereale), and barley (Hordeum vulgare) (Kansas State Board of Agriculture 1977). Often, wet periods in the fall make crops grown on poorly drained clay soils unharvestable, and they become magnets to feeding waterfowl. Even when not flooded, the crops in many localized fields are often eaten or trampled by waterfowl.

History and Description of the Marais des Cygnes WMA

The Marais des Cygnes valley was historically rich in furbearing animals and heavily used by waterfowl. The area was settled by French trappers and named Marais des Cygnes, which means Marsh of the Swans (Gasswint 1981). An article in the Pleasanton Observer Enterprise (1953) quoted then Kansas Fish and Game Commissioner Dave Leahy as saying, "records indicate that in earlier times, the Marais des Cygnes River bottomlands served to attract thousands upon thousands of waterfowl to eastern Kansas during the spring and fall migration periods." Prior to the development of the MDCWMA, there were numerous private waterfowl hunting clubs in the area (Gasswint 1981). Through the 1940's two clubs were located on what were then called Decker Lake and Reese Lake, which are old oxbow lakes now inundated by Unit A on the MDCWMA (R.A. Warhurst, pers. commun.).

The Marais des Cygnes Waterfowl Refuge, as it was first known, was built by the Kansas Forestry, Fish, and Game Commission

with the aid of federal funds through the Pittman-Robertson Act. Land purchasing began in spring 1953, and construction got underway early in 1955. The lake and marsh areas were created by constructing a system of dikes around low lying marshy areas. Trapping of flood waters at the time the river overflowed was the main water supply. Units A (244 ha) and B (176 ha) were completed in 1955, with Unit G (197 ha) being finished in 1958, the first year waterfowl hunting was permitted. The vegetation in these three units originally consisted mostly of timber. Species included pecan (*Carya pecan*), elms (*Ulmus* spp.), ashes (*Fraxinus* spp.), oaks (*Quercus* spp.), hickories (*Carya* spp.), black walnut (*Juglans nigra*), cottonwoods (*Populus* spp.), locusts (*Robinia* spp.), soft maples (*Acer* spp.), basswood (*Tilia americana*), and ironwood (*Ostrya virginiana*) (Schwilling 1958).

Management in the beginning was directed toward maintaining a stable water level, until such time as physical development made manipulation of water levels possible. Almost all trees had died by the third year of flooding. Aquatic plants such as pondweeds (*Potamogeton* spp.), duck potato (*Sagittaria latifolia*), bulrush (*Scirpus* spp.), and smartweed (*Polygonum* spp.), flourished after the trees died (Schwilling 1958).

The original management plan for the Area called for it to be managed as a feeding and resting area for migratory waterfowl. Secondary objectives were to provide habitat for wintering waterfowl, and to provide quality public hunting. To accomplish this, Unit B was open for public hunting while Units A and G were designated refuge areas (M.D. Schwilling, unpubl. rep.). In 1964,

the Area supported 2,035 hunter use-days and produced a harvest of 1,053 waterfowl, for 0.52 birds/hunter use-day. In 1968 Units A and B were open to hunting and Unit G was refuge. Unit B was made the refuge in 1974 and Unit G opened to hunting (R.A. Warhurst, pers. commun.). Unit E (55 ha) was constructed in 1968. In 1974, Units F1 (46 ha) and F2 (193 ha) were completed, followed by Units C1 (32 ha) and C2 (75 ha) in 1979 (Gasswint 1981). Marshes in Units E, F, and C are classified as Palustrine Emergent Wetlands (Cowardin et al. 1979).

Currently the MDCWMA totals 2,894 ha. Of this total, woodland accounts for 1,094 ha, marsh 1,053 ha, cropland 445 ha, riparian timber 203 ha, and grassland 40 ha. Major woody species include bur oak (Quercus macrocarpa), pin oak (Quercus palustris), kingnut hickory (Carya laciniosa), pecan, silver maple (Acer saccharinum), sugar maple (A. saccharum), and green ash (Fraxinus pennsylvanica) (Gasswint 1981). Dominant vegetation in the marshes includes rice cutgrass (Leersia oryzoides), wild millet (Echinocloa crusgalli), nodding smartweed (Polygonum lapathifolium), yellow nutsedge (Cyperus esculentus), pigweed (Amaranthus retroflexus), and common cocklebur (Xanthium strumarium)(Gasswint 1981). The first four of the above species are preferred food for waterfowl, and are used heavily during migration (McAtee 1918, Mabbott 1920, Kubichek 1933, McAtee 1939). Periodic rotational drawdowns are used as a management tool to stimulate growth of these emergent plants.

The third food source for ducks at the MDCWMA is invertebrates. While no studies have been conducted on the Area to determine

species of invertebrates most abundant, data from other similar areas can be applied. The relationship between invertebrates and vegetation suggests there may be major faunal shifts with vegetative succession (Reid 1985). Voights (1976) documented that isopod and snail biomass increased as emergent and dead vegetation increased, while midges and copepods dominated more open areas. Despite the wide diversity of species present in most natural or impounded wetlands, certain taxonomic groups are usually dominant. Gastropods, and members of the order Oligochaeta and family Chironomidae in the order Diptera made up 72.9% of the invertebrates in an Iowa marsh (Tebo 1955). These along with Culicidae larvae presumably make up a large portion of the invertebrate biomass in the marshes at the MDCWMA.

Crops planted on the MDCWMA include corn, milo, red clover (trifolium pratense), wheat, and oats. Approximately 100 ha are planted by Area personnel, with 345 ha farmed by sharecroppers. A portion of these crops are left standing for use by wildlife in the area (Gasswint 1981).

The number of waterfowl hunters using the MDCWMA has dropped over the last few years, remaining below the 20-year average of 3,878 for the past several years. The low was 1,156 hunters in 1980, and the high was 7,726 in 1970. Waterfowl harvest ranged from 726 in 1963, to 6,057 in 1967, with a 20-year average of 2,926 (Table 2) (R.A. Warhurst, unpubl. rep.). If six shotgun cartridges are expended per duck bagged [national average for 1967-1972 (USFWS 1976)] approximately 17,556 shells are fired over the MDCWMA marshes annually. A typical 12 gauge cartridge contains

Table 2. Waterfowl hunting season results on the Marais des Cygnes Wildlife Management Area 1963 - 1984[a].

Year	Hunters	Harvest
1963	1,924	726
1964	2,035	1,193
1965	2,339	2,095
1966	4,541	4,443
1967	5,453	6,057
1968	3,926	2,092
1969	5,314	5,966
1970	7,726	4,664
1971	7,280	3,963
1972	5,099	3,235
1973	4,524	2,942
1974	4,808	2,030
1975	5,241	2,739
1976	--[b]	--
1977	--	--
1978	3,160	2,325
1979	2,649	1,775
1980	1,156	1,255
1981	2,179	2,889
1982	2,772	2,606
1983	2,034	1,941
1984	3,405	3,589
Average	3,878	2,926

[a]Does not include September teal season data.

[b]No data available.

200 No. 4 lead pellets (Lowry 1978), which means that 3.4 million pellets are deposited annually in the Area wetlands. Restricting this deposition to non-refuge marshland results in approximately 4,000 pellets being added to each ha of marsh annually. Because hunting is not uniform over a marsh (Hanson 1976) some areas receive many times this number of pellets while other areas receive far fewer.

Temporary blinds may be erected by hunters out of local materials, but must be removed after the hunting season. Steel shot has been required for all waterfowl hunting with 12 gauge guns since 1979 and with all gauges since 1980 (R.A. Warhurst, unpubl. rep.).

History and Description of the Boicourt Shooting Club

The Boicourt Shooting Club was established in 1898 and incorporated in 1902. It was a popular spot for waterfowl hunting from the turn of the century, and was the major area in the vicinity for waterfowl use (M.R. Thiessen, pers. commun.). An article in the Kansas City Star (1953) stated that Boicourt has been a favorite duck hunting spot for Kansas City men for 60 years or more. Through the 1940's and 1950's the Boicourt Hunting Association had a membership of 20. Current membership stands at 25 (M.R. Thiessen, pers. commun.).

The vegetative composition and the soil types of the club are similar to those of the MDCWMA. The club encompasses 120 ha, and the marshes are divided by dikes into units in which the water level can be controlled by gravity flow. Each unit usually is

drained every year to allow planting of agricultural crops or to allow moist soil plants to germinate and grow for waterfowl food.

Permanent hunting blinds have been erected in all of the units, and have been in place for 10-15 years. Most of the hunting has occurred in the East Feed Lake (14 ha) and South Feed Lake (26 ha) Units (M.R. Thiessen, pers. commun.).

The 16-year average annual waterfowl harvest at Boicourt is 177 ducks. The average has risen to 263 over the past 3 years, however it was only 42 the 4 years previous to that. The range of annual harvest was from 13 in 1980-81 to 344 in 1984-85 (Table 3) (Boicourt Shooting Club, unpubl. data). Using similar calculations to those used for the MDCWMA results in a figure of 2,800 pellets/huntable ha/year deposited in club marshes.

History and Description of the Patterson Duck Club

The Patterson Duck Club was formed in 1920 and some of the marshes have been regularly hunted for ducks with lead shot ever since. Through the 1930's and 1940's anywhere from four to eight people were involved in hunting there. The club was expanded in 1952, and the membership has remained at 16 since 1959. However, many of these 16 do not regularly hunt, and some may go a whole waterfowl season without hunting there (W.A. Anderson, Jr., pers. commun.).

Today, the Patterson Club consists of 300 ha, 30 ha of which is huntable marsh habitat divided into five units. The water level in each unit can be controlled by gravity flow control structures. The entire area lies along the North Sugar Creek

Table 3. Annual waterfowl harvest at the Boicourt Shooting Club from 1967-1984, and the Patterson Duck Club from 1980-1984.

Year	Harvest	
	Boicourt	Patterson
1967	298	
1968	162	
1969	208	
1970	305	
1971	290	
1972	--[a]	
1973	--	
1974	294	
1975	108	
1976	73	
1977	132	
1978	20	
1979	56	
1980	13	397
1981	77	385
1982	191	391
1983	253	404
1984	344	423
Average	177	400

[a]No data available

floodplain, and because of such, the club is similar in vegetative composition and soil type to the MDCWMA.

The McKee Unit (4.5 ha) and the Smartweed Unit (11.3 ha) have been the most heavily hunted units during the past 5 years. The smallest two units, East Beaver (2 ha) and West Beaver (2.8 ha) have received the least hunting pressure during that time. However, hunting has occurred in the West Beaver Unit since 1920 and it has never been cultivated. Most of the units are drained every year to allow disking and crop planting or to allow moist soil plants to grow (W.A. Anderson, Jr., pers. commun.).

An average of 400 ducks have been harvested on the Patterson Club during the past 5 years, with 109 from the McKee Unit and 137 from the Smartweed Unit (Table 3). Considering the relatively small amount of huntable marsh area, a very high number of pellets/ha are deposited annually here. Using the same figures as used for the MDCWMA produces a total of 15,480 pellets/huntable ha/year. Permanent blinds are also located in most marshes, greatly increasing the potential pellet density in some localized areas.

Other Hunting Clubs and Large Water Areas in the Vicinity

Other private hunting clubs exist in the immediate area besides the two studied in this research. The Ottawa Club has been in existence for most of the past 50 years. It is approximately 60 ha in size, and is located immediately south of Boicourt Lake and east of MDCWMA Unit E (Fig. 1). Currently it has a membership of five, although it has been slightly higher in the past (R.A. Warhurst, pers. commun.).

The Oxbow Club is approximately 50 ha in size and has 12-14 members. It has been in existence since before the MDCWMA was developed and is located adjacent to and southwest of the Patterson Club (Fig. 1)(R.A. Warhurst, pers. commun.).

LaCygne Lake, a 1,053 ha lake used as a source of cooling water for an electrical generating plant, lies 10 km north of the MDCWMA. The lake area is used by migratory waterfowl in both the spring and fall. No fluctuation of the lake water level is permitted, however waterfowl use of the area is significant due to the warm water discharge which maintains some ice-free areas at all times (Gasswint 1981). In recent years, from 35 to 45 thousand mallards have wintered on the LaCygne Power Plant Lake (R.A. Warhurst, unpubl. rep.). Waterfowl hunting is allowed on a small portion of the north end of the lake.

Waterfowl Use of the Marais des Cygnes WMA

Local production of waterfowl is limited primarily to wood ducks. Smaller numbers of nesting mallards, blue-winged teal (*Anas discors*), and giant Canada geese (*Branta canadensis maxima*) are observed each year. The Kansas Fish and Game Commission initiated a project to establish a local nesting flock of giant Canada geese on the Area in 1980. The current population level is 1,300 geese (K. Karrow, pers. commun.).

During fall migration, concentrations of ducks have been as high as 100,000 in 1968. Peak concentrations have ranged from 30,000 to 83,800 the last 5 years. At the beginning of October, wood ducks, blue-winged teal, and green-winged teal are the most

common ducks on the Area, numbering from 1,500 to 4,000. Wood duck and blue-winged teal numbers then decline steadily through the season. From late October on, mallards are by far the most numerous species, reaching a peak of 30,000 to 80,000 in December. Average peaks and dates of peaks for other species are as follows: pintail, 2,100 in late October; green-winged teal, 5,000 anywhere from early November to early December; American wigeon, 1,400 in early November; gadwall, 1,500 in November; and ring-necked duck, 1,800 in early November. All other species averaged less than 500 for a peak concentration (R.A. Warhurst, unpubl. reps.).

The migration corridor that is used by most species found at the MDCWMA originates usually in Saskatchewan and travels in a southeasterly direction through eastern North Dakota, eastern South dakota, eastern Nebraska to eastern Kansas. From there the ducks continue south to the Gulf coast of Texas and Louisiana (Bellrose 1976). This migration corridor is part of the Central Flyway.

Most ducks in the area rest on the refuge units during the day and feed in the marshes at night. As the season progresses, many mallards fly to nearby grain fields to feed, instead of feeding in the marshes. After the marshes freeze, many mallards spend their time resting on the LaCygne Power Plant Lake, which stays open through the winter.

Marshes on the MDCWMA usually have started to thaw by the time pintails arrive on their migration northward in mid-February (R.A. Warhurst, pers. commun.). Spring populations of waterfowl are generally higher than those in the fall. In the spring of

1980, a peak of nearly 200,000 ducks and 75,000 geese utilized the area (Gasswint 1981). The duck use in spring increased rapidly immediately after the MDCWMA was built, and has remained fairly constant. A newspaper account from the Topeka Daily Capitol in 1958 stated that there were as many as 200,000 ducks using the MDCWMA at one time during the spring.

Bald eagles are common on the MDCWMA during fall and early winter. In 1975, 241 eagle use-weeks were recorded (L. Fox, unpubl. data). On 4 January 1977, 22 bald eagles were sighted (H. Moore, unpubl. data), and as many as 31 bald eagles have been seen on the Area at one time (Gasswint 1981).

METHODS AND MATERIALS

Marsh Substrate Sampling

Substrate samples were collected from the three study areas during May and June 1983, and April, May, and June 1984. In 1983, plots were established on the MDCWMA Units A, C2, and F2, Boicourt's East Feed Lake (EFL) and South Feed Lake (SFL), and Patterson's Smartweed Unit and McKee Unit. These units traditionally averaged the greatest number of ducks harvested from them (and probably shotgun shells expended) out of all the units on the three areas (Boicourt Shooting Club, unpubl. data, Patterson Duck Club, unpubl. data, R.A. Warhurst, unpubl. rep.) (Table 4).

Plot sites were chosen to maximize the amount of shot found. The MDCWMA area manager pointed out general preferred hunting locations on each of the units sampled on that area to accomplish this objective. Permanent hunting blinds served as the general focus of plot placement on the private clubs. Water depths around the sample plots ranged from 0 (dry ground) to 90 cm.

Each unit had a unique chronology of drawdowns and cultivations during the three years preceding the May 1983 sampling. Each of the units studied could be drained by gravity flow, a process which takes from one week to one month depending on the size of the unit. The water in MDCWMA Unit A was held high through spring 1983, and was drained off in June of both 1982 and 1981. Unit C2 on the MDCWMA was dewatered in late April 1983. The water in this unit was held high in both 1982 and 1981. Unit F2 was drained during early April 1983. During both 1982

Table 4. Average annual number of waterfowl harvested on each unit that was soil sampled, harvest on a per hectare basis, average number of pellets estimated deposited per hectare, and percentage of each study sites' total waterfowl harvest killed on each unit.

Area	Unit	Average harvest	Average harvest/ha	Average no. pellets/ha	Avg.% of Area's total harvest
MDCWMA	A	1,250	5.1	6,061	46
	C2	345	4.6	5,464	13
	F2	268	1.4	1,666	10
	F1	227	4.9	5,862	8
Boicourt	SFL	163	6.3	7,447	62
	EFL	64	4.6	5,430	24
Patterson	Smartweed	137	12.1	14,796	34
	McKee	109	24.2	25,898	27

and 1981 the water level was held at full pool.

Water in both the Smartweed and McKee Units on the Patterson Club was drained off annually. The Smartweed Unit was disced once in the last 5 years (1983), and planted to milo. The McKee Unit was disced 3 of the last 5 years, and milo was planted after each discing (Patterson Duck Club, unpubl. data).

The EFL and SFL Units on the Boicourt Club are also drained annually. Each Unit has been cultivated once in the last 10 years. The EFL was plowed and planted to milo and Japanese millet in 1982. The SFL was disced three times in 1981 and also had milo and millet planted in it (Boicourt Shooting Club, unpubl. data). All units that are drained are reflooded for the waterfowl hunting season.

Substrate samples were collected using a welded lead and steel core sampler 5.72 cm in diameter. This sampler was pushed into the substrate to a depth of 10-12 cm, pulled out, and the core ejected out the end of the sampler by the force of a steel plunger pushed by hand against the sample.

Plots consisted of straight lines extending 50 m in each of the eight 45° compass directions from a center point. Fifty core samples were taken from each plot. The exact location of each sample on a particular plot was determined using a five-digit random numbers table (Snedecor and Cochran 1980). First, a numerical value of 1-8 was randomly assigned to each of the eight compass directions, with no value being repeated. sample sites were then selected from a table of random numbers: the first digit determined compass direction, and the next two digits determined

the distance out from the plot center point. If the direction digit was 0 or 9 or the distance number greater than 50, the next series of five digits was examined, until 50 sample points had been determined.

Three plots were used for sampling MDCWMA Unit A, two each on Units C2 and F2, and one on each of the four private club units. Likely-looking hunter hiding spots in the popular hunting areas pointed out by the MDCWMA area manager were used as center points for plots on the MDCWMA. Permanent hunting blinds in the most heavily hunted units were used as plot center points on the private clubs.

Two to three persons were needed to perform the sampling procedure in the field. Deeper water made sampling much more difficult than sampling in shallow water or dry ground. In deep water (>30 cm) a 12 foot flat-bottomed boat was used to carry all equipment to the plot site. One person held the boat and wrote data on the sample bags. The second person collected the soil core with the sampler. The third person held the sample bag open while the soil core was being ejected into it. Heavy duty "Zip-Lock" storage bags were used to hold individual soil cores. Data recorded on sample bags included date, plot number, direction-distance number, and whether it was collected under water, in vegetation, or on dry ground. All samples from a particular plot were stored together in heavy duty plastic bags.

In 1984, two plots on MDCWMA Unit Fl were substituted for the two plots on Unit F2. This was done to take advantage of low water levels on Unit Fl as compared to Unit F2. The number of

ducks harvested on Unit F1 was approximately equal to that of Unit F2. All other units sampled in 1983 were sampled again in 1984, using the same number of plots in each unit as was done previously. The 1984 plots were not placed in the exact spots of the 1983 plots.

Water levels during the 1984 sampling period were much more uniform than the year before, ranging from 0 (dry ground) to 25 cm. Water in Unit F1 was drained in April 1984 and June 1982, and held high during 1983 and 1981. Unit A on the MDCWMA also was dewatered in April 1984. MDCWMA Unit C2 was drained in January 1984. All four units on the two private clubs were drained in late spring 1984.

A new core sampler was constructed for the second year of substrate sampling, based on a design by Quist and Kirby (1978) (Fig. 3). The main components were plastic PVC pipe, wooden dowels, rubber stoppers, and a threaded steel rod. It operated much more smoothly than the sampler used previously, and weighed 0.5 kg and floated as compared to the steel and lead sampler which weighed 4.8 kg and sank in water. Sample depths were again 10-12 cm, and the core sample was ejected out the end of the sampler in similar fashion to 1983.

Plot design was similar to that of 1983, using 50-m straight lines diverging in the eight 45° compass directions from a center point. However, 75 core samples were collected from each plot instead of 50. The 75 sample points were determined from a random numbers table, using the same method as 1983.

Plots were placed in the same types of areas during 1984 as during 1983. On the MDCWMA, plot center points were placed in

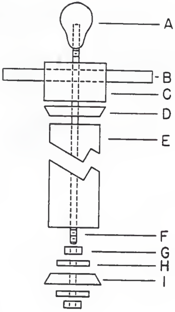

Fig. 3. Design of the core sampler used during 1984: (A) wooden file handle; (B) 2.54-cm x 30-cm wooden dowel; (C) PVC coupling for 5.08-cm pipe; (D) one-hole rubber stopper (no. 11.5, 63 mm o.d.); (E) 76-cm length PVC plastic pipe (5.08 cm i.d.); (F) 6-mm x 92-cm steel rod threaded 8 cm both ends with standard thread; (G) 6-mm nut (2 needed); (H) 4-cm flat washer with 6-mm hole (2 needed); (I) one-hole rubber stopper (no. 11, 56 mm o.d.)(Quist and Kirby 1978).

between two or three likely-looking hunter hiding spots in popular hunting areas on each unit. Similarly, on the private clubs, plot center points were placed in between two or three permanent hunting blinds. Where only one blind was present in a unit, the center point was placed 50 m in front of the blind. This allowed for core samples to be collected up to 100 m from the blind.

One to two persons were all that were required to sample the substrate the second year. Because sample points were determined before going out to the field, the sample storage bags were labeled beforehand. For a particular plot, all sample bags with the same compass direction were placed together, and each direction placed in numerically ascending order. Nasco 266.2 ml plastic "Whirl-Pak" bags were used for core sample bags, thus eliminating a problem of dirt getting into the zip-lock track. The mouth of these whirl-pak bags fit snuggly over the end of the core sampler barrel, making it unneccessary for a person to hold the bag while the core was being emptied into it. However, work did move slightly faster if a person held the sample bag open under the sampler barrel, instead of fitting it over the end. A boat was never needed because water depths were always less than 25 cm.

Substrate Analysis

Substrate samples taken in 1983 from plots on MDCWMA Units A, C2, and F2, and on the South Feed Lake Unit of the Boicourt Club were individually placed in a #20 (0.833 mm) sieve screen for analysis. Samples were still moist from being recently collected.

Core samples from plots on the East Feed Lake Unit on Boicourt and the Smartweed and McKee Units on Patterson were not analyzed at this time. A garden hose was used to force the mud through the screen, leaving stones, sticks, pieces of vegetation, and pellets behind. This remaining material was searched carefully for shotgun pellets. If a pellet was found, it was verified to be lead or steel with a magnet, and the plot recorded.

X-rays were used to analyze all substrate samples collected during the spring of 1984. A Picker GX 600 x-ray machine, located in the Department of Surgery and Medicine of the College of Veterinary Medicine at Kansas State University, was used to detect pellets present in the samples. Ten "dummy" samples, ranging from water saturated to air dry, were seeded with both lead and steel shot to calibrate for the best exposure, and to discover if variability in sample moisture content would pose any problems. Moisture content made little difference in ability to detect pellets present, and a setting of 200 milliamperes at 0.005 sec and 84 killivolts was chosen as the optimum exposure. There was no difference in results whether samples were inside or outside the plastic bag, so samples were analyzed inside the plastic bag. Samples were placed in cardboard 8-pack soda pop containers to keep them upright while being x-rayed. X-ray film used was a 35 x 43 cm sheet of Du Pont's Cronex 7. Three 8-pack containers fit on one sheet of film, allowing 24 substrate samples to be x-rayed at a time. Film was developed immediately using a Kodak RP X-omat processor, and x-rays were examined on a light table. All samples producing x-rays with positive pellet signatures

(bright white spots) were manually searched thoroughly using the sieve screen and garden hose method to determine if the signatures were true or false positives. All pellets found were determined to be lead or steel with a magnet, and the plot they were recovered from recorded.

A combination of the x-ray and sieve screen methods was used to examine the core samples taken in 1983 from Boicourt's EFL and Patterson's Smartweed and McKee Units. First, all samples were x-rayed and developed as before. Prior to examining the x-rays, however, each sample was searched manually using the sieve method, and all located pellets recorded. The x-ray results were then compared with the manual search results. This provided a check on accuracy of the results from the 1983 sample analysis.

Artificial Seeding and Recovery of Shot

During September 1983, a square of 0.5 ha in area was delineated in the middle of MDCWMA Unit F1 to test if shotgun pellets became unavailable to feeding waterfowl after one year. This area was chosen for a number of reasons. First, it was the deepest part of the unit (60-90 cm), therefore it was assumed that little hunting had traditionally occurred there, resulting in few pellets in the substrate. Second, the soil type was typical of all of the other marsh soils on the MDCWMA. Third, the chronology of drawdowns and floodings were representative of most all of the other units on the MDCWMA. Both lead No. 6 and steel No. 4 shotgun pellets were randomly spread over the entire plot by hand at the rate of 39,520 pellets of each/ha. Water depths ranged from 50-90 cm at the time of seeding.

Substrate core samples from this area were collected one year later (September 1984). This unit was reflooded at the beginning of September, after being drained in April 1984. The same PVC pipe sampler used in the spring of 1984 was used for the fall sample collection. The seeded area was divided into quadrants, and one plot was established in each quadrant. Plot design was similar to that used previously, with 17-m long straight lines extending in the eight 45° compass directions from a center point. The center point of each plot was the center point of each quadrant (Fig. 4).

One hundred twenty-five core samples were collected from each of the four plots. Because there were only 136 possible sample points on each plot, 11 points were determined from a random numbers table to be the points not sampled. This was done using the same three digit direction-distance method as used for the spring substrate sampling.

Water depths ranged from 15-50 cm at the time of sampling, and samples were taken at a substrate depth of 10-12 cm. Core samples were placed in the plastic "Whirl-Pak" bags and x-rayed for examination. This involved the identical setting and techniques as for the spring 1984 samples.

Gizzard Collection at Marais des Cygnes

Gizzards of five species of dabbling ducks were collected on the MDCWMA to search for ingested shot during the 1982-83 waterfowl hunting season. Species sampled included mallard, pintail, green-winged teal, gadwall, and wood duck. These represented the five species harvested in greatest quantity at the

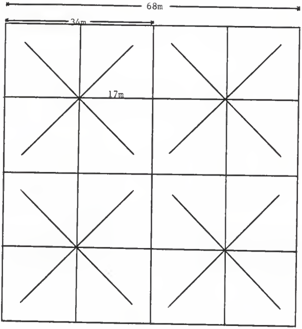

Fig. 4. Design of the plot used to sample the area that had been artificially seeded with shot.

MDCWMA over the past 20 years (R.A. Warhurst, unpubl. rep.). In 1983-84 and 1984-85, gizzards of two diving duck species were collected in addition to the five aforementioned species. These were lesser scaup and ring-necked duck, which were the two most numerous diving duck species harvested over the past 20 years at the MDCWMA (R.A. Warhurst, unpubl. rep.).

Duck gizzards were collected with the voluntary approval of hunters. Collection was done as hunter-killed ducks were processed at the mandatory check station in the MDCWMA headquarters. Gizzards were removed from duck carcasses by making a crosswise slit between the cloaca and sternum and severing the gizzard from the intestines. Gizzards were placed in 88.7 ml or 266.2 ml "Whirl-Pack" bags, labeled (species, date, location of kill, sex, and age in 1982-83 and 1983-84; species, date, location of kill in 1984-85), and stored frozen.

Gizzard Collection at the Private Clubs

Mallard and green-winged teal gizzards were collected at both private clubs during the 1982-83 season. Gizzards of the same seven species sampled the last two years at the MDCWMA were taken from Boicourt and Patterson during 1983-84. Because of poor sample sizes of most species, only mallard gizzards were collected from the two clubs during 1984-85.

Each club was visited two to three times daily on weekends the first two years of the study, and gizzards were collected as members of the Patterson Club or the caretaker of the Boicourt Club cleaned the ducks. The third year a plastic bucket filled with water was left at each clubhouse. As members

of Patterson or the caretaker at Boicourt cleaned mallards, the gizzards were deposited in the buckets. Buckets were picked up at the end of each day (four days/week) and gizzards transferred to plastic bags labeled as to species, date and location of kill. Gizzards were then stored frozen.

Examination of Gizzard Contents

Contents of all gizzards collected during 1982-83 and 1983-84 were initially examined by a visual method only. Prior to analysis, each gizzard was given a number which was recorded on data sheets, along with species, age, sex, weight, date of collection, and location of kill. Gizzards were thawed, cut open under a gentle flow of water, contents washed into a petri dish, and excess water poured off. Contents were searched using a probe for approximately four to five minutes each, or until it was believed that no pellets were missed. If a pellet was found, the inner wall and outer muscle of the gizzard were probed for holes, indicating the pellet had been fired into the duck. Other clues, such as pellet wear, appearance of pellet (angular, pitted, dark blue-gray, or shiny), and the presence of a feather wad inside the gizzard were used to decide if a pellet had been fired in (Welch 1976, Wooley 1979, Anderson and Havera 1985). Pellets were determined to be lead or steel with a magnet, recorded as ingested or fired in on the data sheet, then placed in alcohol-filled 16 ml labeled vials with the remaining gizzard contents for storage. Vials were labeled as to species, gizzard number, and year collected.

X-rays were used to examine contents of gizzards collected during 1984-85. The initial steps in analyzing these gizzards

were similar to those described for the visual method, up to the point of searching for pellets. Only large pellets (unworn) were searched for in 1984-85, greatly reducing the length of time gizzard contents were examined. If a large pellet was found, clues were again used to determine if the pellet had been fired in. This determination of ingested or fired in was recorded, and pellets placed along with the remaining gizzard contents in vials identical to those used the first two years.

A Picker GX-600 x-ray machine was used to examine the gizzard contents for shot. Twenty vials containing various amounts of alcohol, gizzard content material, and shotgun pellets (lead and steel of various sizes) were x-rayed at a number of settings to calibrate the machine and to determine what difference, if any, these factors would make in the resulting x-ray. None of the variables had any effect, and a setting of 200 milliamperes at 0.005 sec and 66 killivolts was chosen as giving the best picture. Film used was a 35 x 43 cm sheet of du Pont's Cronex 7. Vials were held upright in a 12.5 x 30 cm 40-capacity polypropylene test tube holder. Three such holders were placed on a single sheet of film, resulting in 120 vials x-rayed per sheet of film. Film was developed using a Kodak RP X-omat processor, and the x-ray observed on a light table. All vials showing possible positive results (bright white spots) were emptied and manually searched thoroughly to determine if the x-ray signatures were true or false positives. Pellets were determined to be lead or steel by use of a magnet, then returned with the gizzard contents to the vial for storage.

Gizzard contents from 1982-83 and 1983-84 that had been

stored in vials were reexamined using x-rays. The identical procedure as that just described for contents of 1984-85 collected gizzards was followed. This provided for a check on the accuracy of the visual method.

Liver Collection

Livers were removed from a sample of mallards harvested at the MDCWMA during 1984-85 while the gizzards were being removed. The gizzard and matching liver were placed in separate 266.2 ml "Whirl-Pak" bags and numbered identically. The bags were labeled as to date and location of kill and stored frozen.

Liver Analysis

Liver lead analyses were performed in the Comparative Toxicology Laboratories of the College of Veterinary Medicine at Kansas State University. A colorimetry test (Hammond et al. 1965) was used to determine lead content in waterfowl livers. Livers were macerated with a Kinematica GmbH PCU-2-110 polytron homogenizer, and 500 mg of homogenized tissue were put in a test tube with 10 ml of 5% trichloroacetic acid (TCA) for 1 hour. The mixture was centrifuged for 10 min at 1,350 g's of force (2,500 rpm's) with a Damon ICE HN-SII centrifuge, and then more TCA, an alkaline reagent, and a dithizone solution were added to the supernatant. The resulting colored solution was then compared to a standard colorimetric lead concentration in liver color chart to determine liver lead content. The step by step procedure used for the liver lead analysis, as well as directions for solution preparation and names and addresses of

companies from where the chemicals were obtained are in Appendices A-C.

Statistical Analysis of Gizzard Data

Chi-square contingency tables were set up to determine significant differences between the proportion of ducks ingesting steel and lead shot. Comparisons were made between species, between study sites, and between years within a species.

RESULTS

Marsh Substrate Sampling

Forty-three shotgun pellets were found in 1,375 soil samples collected on 22 plots in 2 years. Of the 43 pellets, 35 were lead and 8 were steel. The greatest number of pellets found in one plot was nine on MDCWMA Unit A in 1984 (Table 5).

Fifty soil samples were collected from each of the 11 plots in 1983. One lead pellet was found in the 50 samples from plot #1 on MDCWMA Unit A in 1983. No pellets were found in Unit A plot #2, and one steel and two lead pellets were found in samples from plot #3. No pellets were discovered in 100 soil samples from the two plots on MDCWMA Unit F2, or the two plots on MDCWMA Unit C2 in 1983 (Table 5). Soil samples from the seven plots on Units A, F2, and C2 were analyzed by visual examination only. Two plots of 50 soil cores each were sampled at each private club in 1983. These cores were analyzed by x-ray followed by visual examination of all samples before x-rays were observed. Visual examination produced two lead pellets from the 100 samples at Boicourt, and one lead pellet from the 100 samples at Patterson. X-rays located four lead pellets in the same 100 soil cores from Boicourt, and three lead pellets from the same 100 cores from Patterson. No steel pellets were found in any of the samples from either private club (Table 5).

All soil samples collected in 1984 were analyzed using x-rays. Seventy-five soil cores were sampled on each plot in 1984. Nine pellets, six lead and three steel, were found in samples from MDCWMA Unit A plot #1. Five lead and three steel

Table 5. Number of shotgun pellets found and density of shot in soil collected from all three study sites in 1983 and 1984.

			1983				1984			
			Pellets found				Pellets found			
Area	Unit	Plot no.[a]	Lead	Steel	Pellets/m^2	Pellets/ha	Lead	Steel	Pellets/m^2	Pellets/ha
MOCWMA	A	1[b]	1	0	7.75	77,500	6	3	58.95	589,500
	A	2[b]	0	0	0	0	5	3	52.50	525,000
	A	3[b]	2	1	23.35	233,500	6	0	39.40	394,000
	Avg.A				10.35	103,500			50.30	503,000
	F2	1[b]	0	0	0	0	--[c]	--[c]	--[c]	--[c]
	F2	2[b]	0	0	0	0	--[c]	--[c]	--[c]	--[c]
	Avg.F2				0	0			--[c]	--[c]
	F1	1	--[d]	--[d]	--[d]	--[d]	1	1	13.10	131,000
	F1	2	--[d]	--[d]	--[d]	--[d]	0	0	0	0
	Avg.F1				--[d]	--[d]			6.55	65,500
	C2	1[b]	0	0	0	0	0	0	0	0
	C2	2[b]	0	0	0	0	0	0	0	0
	Avg.C2				0	0			0	0
Boicourt	EFL	1	2 (1)[e]	0	15.50	155,000	2	0	13.10	131,000
	SFL	1	2 (1)	0	15.10	155,000	2	0	13.10	131,000
Patterson	Smartweed	1	2 (1)	0	15.10	155,000	2	0	13.10	131,000
	McKee	1	1 (0)	0	7.75	77,500	1	0	6.55	65,500

[a]Even though plot numbers are identical for both 1983 and 1984 samples, they were not placed in the same location from one year to the next.

[b]Soil samples from these plots in 1983 were analyzed by visual examination only.

[c]Not sampled in 1984.

[d]Not sampled in 1983.

[e]Number in parentheses represents number of pellets found by visually examining samples.

pellets were located in the 75 samples from plot #2 on Unit A. Samples from Unit A plot #3 produced six lead and no steel pellets. Two pellets were found in samples from plot #1 on MDCWMA Unit F1, one lead and one steel. No pellets were found in plot #2 of Unit F1 in 1984. No pellets were found in 150 samples from the two plots on MDCWMA Unit C2 (Table 5).

Four lead pellets were located in the 150 samples from the two Boicourt plots, two pellets in each plot, two lead pellets were found in samples from the Smartweed Unit on the Patterson Club, and one lead pellet was found in the samples from the 1984 plot on Patterson's McKee Unit. Again no steel pellets were found in samples from either private club (Table 5).

Each 1983 plot of 50 core samples represented an actual sample of $0.13m^2$ of soil, and the 75 samples per plot in 1984 was an actual sample of $0.15m^2$. The number of pellets found per plot was extrapolated to pellets/m^2 and pellets/ha using the $0.13m^2$ and $0.15m^2$ figures. One pellet per plot extrapolated to $7.75/m^2$ (77,500/ha) for 1983 samples and to $6.55/m^2$ (65,500/ha) for 1984 samples. When no pellets were found in a plot, pellet density was reported as zero. Zero was used with the understanding that pellet density actually could be in the range of 0-$7.75/m^2$ in 1983 and 0-$6.55/m^2$ in 1984. Zero was selected because no justification was found to use any other density within the ranges (Table 5).

Plot #3 on MDCWMA Unit A had the highest pellet density of any 1983 plot at $23.32/m^2$ (233,500/ha). The average pellet density of the three 1983 Unit A plots was $10.35/m^2$ (103,500/ha). MDCWMA Units F2 and C2 each averaged 0 pellets/m^2 in 1983.

Both 1983 plots on the Boicourt Club had a pellet density of $15.55/m^2$ (155,000/ha). The Smartweed Unit on the Patterson Club also had $15.55/m^2$ and the McKee Unit had 7.75 pellets/m^2 (77,500 pellets/ha) (Table 5).

Recovery of Artificially Seeded Shot

The 0.5 ha plot that was artificially seeded with shot was broken into quadrants for sampling. One plot consisting of 125 core samples was placed in each quadrant. Ten pellets were found in the 500 core samples from the four plots. Six of the ten pellets were steel and four were lead. Ten pellets in 500 core samples extrapolates to 9.9 pellets/m^2 (99,000/ha). Use of the normal approximation to the binomial distribution confirms the null hypothesis that there has been no loss of pellets from the top 10-12 cm of substrate during one year ($Z=0.77$, $P>0.05$).

Shot Incidence in Gizzards

Gizzards from 1,902 ducks were collected from all three study sites during three years. Of the 1,902, 1,683 (88.5%) were collected at the MDCWMA, 136 (7.1%) at Patterson, and 83 (4.4%) at Boicourt. Mallard gizzards accounted for 934 (49%) of the 3-year total and 754 (45%) of the 3-year MDCWMA total. At Patterson, mallard gizzards made up 108 (79%) of the 136 gizzard total, with the remainder being green-winged teal (16), wood ducks (6), and gadwall (6). Seventy-two (87%) of the 83 gizzards from Boicourt were from mallards. Seven were collected from green-winged teal, while one each was collected from a pintail, wood duck, gadwall, and lesser scaup. Green-winged teal gizzards were second in number to mallards at MDCWMA with

366, followed by wood ducks (148), pintail (139), gadwall (130), ringnecks (86), and lesser scaup (60) (Table 6).

In 1982-83, 746 gizzards were collected (Table 7). Thirty came from Boicourt, 46 from Patterson, and 670 from the MDCWMA. Twenty-eight (4.2%) of the 670 ducks from the MDCWMA were found with ingested shot in their gizzard (lead or steel); 18 (2.7%) contained steel shot and 10 (1.5%) contained lead shot. Not all species ingested shot at the same rate. Mallards had the highest rate of shot incidence of the five species collected. Twenty-two (6.6%) of the 337 mallards sampled from the MDCWMA in 1982-83 contained ingested shot in the gizzard; 14 (4.2%) had steel and 8 (2.4%) had lead. Gadwalls had the second highest ingested shot incidence. Three (5.6%) out of 54 gadwall gizzards contained shot, and all three had steel shot. Only two (2.8%) of the wood duck and one (1.4%) of the pintail gizzards contained shot out of 69 and 70 respectively. No green-winged teal out of the 140 sampled in 1982-83 from the MDCWMA contained ingested shot in the gizzard.

The 23 mallard gizzards collected from Boicourt in 1982-83 produced one (4.3%) with ingested shot. This one gizzard contained lead shot. None of the seven green-winged teal sampled contained ingested shot (Table 7). Thirty-two mallard gizzards were collected at the Patterson Club in 1982-83 and 3 (9.4%) contained ingested lead shot while none contained steel shot. No green-winged teal of the 14 sampled contained ingested shot (Table 7).

Three hundred seventy-nine ducks were sampled in 1983-84, with 325 collected from the MDCWMA, 24 from Boicourt, and 30 from Patterson (Table 8). Eight (2.7%) of the ducks from the

Table 6. Incidence of ingested steel and lead pellets in duck gizzards collected from the three study sites during the period 1982-1985.

Species of waterfowl	MDCWMA			Boicourt			Patterson		
	Gizzards	No. with shot (%)		Gizzards	No. with shot (%)		Gizzards	No. with shot (%)	
		Steel	Lead		Steel	Lead		Steel	Lead
Mallard	754	30 (4.0)	24 (3.2)	72	1 (1.4)	4 (5.6)	108	1 (0.9)	11 (10.2)
Pintail	139	0 (0.0)	1 (0.7)	1	0 (0.0)	0 (0.0)	--[a]	--	--
G.W. teal	366	0 (0.0)	1 (0.3)	7	0 (0.0)	0 (0.0)	16	0 (0.0)	0 (0.0)
Wood duck	148	1 (0.7)	1 (0.7)	1	0 (0.0)	0 (0.0)	6	0 (0.0)	0 (0.0)
Gadwall	130	5 (3.8)	0 (0.0)	1	0 (0.0)	0 (0.0)	6	0 (0.0)	0 (0.0)
L. Scaup	60	0 (0.0)	2 (3.3)	1	0 (0.0)	0 (0.0)	--	--	--
Ringneck	86	2 (2.3)	1 (1.2)	--	--	--	--	--	--
Totals	1,683	38 (2.3)	30 (1.8)	83	1 (1.2)	4 (4.8)	136	1 (0.7)	11 (8.1)

[a]No gizzards collected

Table 7. Incidence of ingested steel and lead pellets in duck gizzards collected from the three study sites during 1982-83.

Species of waterfowl	MDCWMA			Boicourt			Patterson		
	Gizzards	No. with shot (%)		Gizzards	No. with shot (%)		Gizzards	No. with shot (%)	
		Steel	Lead		Steel	Lead		Steel	Lead
Mallard	337	14 (4.2)	8 (2.4)	23	0 (0.0)	1 (4.3)	32	0 (0.0)	3 (9.4)
Pintail	70	0 (0.0)	1 (1.4)	--[a]	--	--	--	--	--
G.W. teal	140	0 (0.0)	0 (0.0)	7	0 (0.0)	0 (0.0)	14	0 (0.0)	0 (0.0)
Wood duck	69	1 (1.4)	1 (1.4)	--	--	--	--	--	--
Gadwall	54	3 (5.6)	0 (0.0)	--	--	--	--	--	--
L. Scaup	--	--	--	--	--	--	--	--	--
Ringneck	--	--	--	--	--	--	--	--	--
Totals	670	18 (2.7)	10 (1.5)	30	0 (0.0)	1 (3.3)	46	0 (0.0)	3 (6.5)

[a]No gizzards collected

Table 8. Incidence of ingested steel and lead pellets in duck gizzards collected from the three study sites during 1983-84.

Species of waterfowl	MDCWMA			Boicourt			Patterson		
	Gizzards	No. with shot (%)		Gizzards	No. with shot (%)		Gizzards	No. with shot (%)	
		Steel	Lead		Steel	Lead		Steel	Lead
Mallard	147	2 (1.4)	3 (2.0)	20	0 (0.0)	2 (10.0)	16	0 (0.0)	1 (6.3)
Pintail	17	0 (0.0)	0 (0.0)	1	0 (0.0)	0 (0.0)	--	--	--
G.W. teal	93	0 (0.0)	0 (0.0)	--[a]	--	--	2	0 (0.0)	0 (0.0)
Wood duck	32	0 (0.0)	0 (0.0)	1	0 (0.0)	0 (0.0)	6	0 (0.0)	0 (0.0)
Gadwall	13	2 (15.4)	0 (0.0)	1	0 (0.0)	0 (0.0)	6	0 (0.0)	0 (0.0)
L. Scaup	4	0 (0.0)	0 (0.0)	1	0 (0.0)	0 (0.0)	--	--	--
Ringneck	19	1 (5.3)	0 (0.0)	--	--	--	--	--	--
Totals	325	5 (1.5)	3 (1.2)	24	0 (0.0)	2 (8.3)	30	0 (0.0)	1 (3.3)

[a]No gizzards collected

MDCWMA contained ingested shot. Five of the eight contained steel shot and three contained lead shot. This year gadwall had the highest rate of ingested shot. Two (15.4%) of the 13 gadwall gizzards sampled contained shot, with both of these containing steel shot. One (5.3%) of 19 ringnecks contained steel shot, and five (3.4%) of the 147 mallards had ingested shot in their gizzards. Two of the five mallards with shot had steel shot and three had lead shot. None of the other 146 gizzards representing four species contained any ingested shot.

Two (10.0%) of the 20 mallards gizzards collected at the Boicourt Club in 1983-84 contained ingested shot, and both contained lead shot. Only one gizzard was collected from each of four other species and none held any ingested shot (Table 8). Thirty gizzards were collected from four species at the Patterson Club in 1983-84, and one (3.3%) contained ingested shot. This one shot was lead and was ingested by one of the 16 mallards sampled (Table 8).

In 1984-85, 60 ducks were sampled from the Patterson Club, 29 from the Boicourt Club, and 688 from the MDCWMA, for a total of 777. Fifteen (2.2%) of the 688 gizzards from the MDCWMA contained steel shot and 17 (2.5%) contained lead shot. The majority of ducks ingesting shot were mallards. Twenty-seven (10.0%) of the 270 mallards collected had ingested shot, with 14 (5.2%) containing steel shot and 13 (4.8%) containing lead shot. Two (3.6%) of 56 lesser scaup contained ingested shot (both lead), and two (3.0%) of 67 ringnecks contained shot. One ringneck ingested lead shot and one had ingested steel. A green-winged teal was found with ingested shot for the first

time in the three years. One (0.8%) teal of 133 collected contained an ingested lead pellet. The remaining 162 gizzards collected from pintails, wood ducks, and gadwalls contained no ingested shot (Table 9).

Only mallards were sampled at the two private clubs in 1984-85. Two (6.8%) of the 29 gizzards collected at Boicourt contained ingested shot, with one containing steel shot and one containing lead. Sixty mallards were collected from Patterson, with one (1.7%) having ingested steel shot and seven (11.6%) found with ingested lead (Table 9).

Combining data from all three years at the MDCWMA shows 68 (4.1%) of the 1,683 gizzards collected containing ingested shot; 38 (2.3%) contained steel shot and 30 (1.8%) contained lead shot. Of the 83 ducks sampled from the Boicourt Club, 5 (6.0%) contained ingested shot in their gizzard. The majority of these (4) contained lead shot. The 3-year Patterson Club gizzard total was 136, with 12 (8.8%) found with ingested shot. Eleven (8.1) of the 136 contained lead shot and one (0.7%) contained steel (Table 6).

Mallards had the highest incidences of ingested shot of any species at all three study sites. At the MDCWMA, 30 (4.0%) ingested steel and 24 (3.2%) ingested lead of the 754 sampled. This is a combined ingested shot incidence of 7.2%. Seventy-two mallard gizzards were collected over three years from Boicourt. One (1.4%) was found with ingested steel shot and four (5.6%) with ingested lead. Out of 108 mallards sampled at Patterson, one (0.9%) contained ingested steel and 11 (10.2%) contained ingested lead (Table 6).

Table 9. Incidence of ingested steel and lead pellets in duck gizzards collected from the three study sites during 1984-85.

Species of waterfowl	MDCWMA			Boicourt			Patterson		
	Gizzards	No. with shot (%)		Gizzards	No. with shot (%)		Gizzards	No. with shot (%)	
		Steel	Lead		Steel	Lead		Steel	Lead
Mallard	270	14 (5.2)	13 (4.8)	29	1 (3.4)	1 (3.4)	60	1 (1.7)	7 (11.6)
Pintail	52	0 (0.0)	0 (0.0)	--[a]	--	--	--	--	--
G.W. teal	133	0 (0.0)	1 (0.8)	--	--	--	--	--	--
Wood duck	47	0 (0.0)	0 (0.0)	--	--	--	--	--	--
Gadwall	63	0 (0.0)	0 (0.0)	--	--	--	--	--	--
L. Scaup	56	0 (0.0)	2 (3.6)	--	--	--	--	--	--
Ringneck	67	1 (1.5)	1 (1.5)	--	--	--	--	--	--
Totals	688	15 (2.2)	17 (2.5)	29	1 (3.4)	1 (3.4)	60	1 (1.7)	7 (11.6)

[a]No gizzards collected

The remaining six species each showed 3-year ingested shot incidences of less than 4.0% at the MDCWMA. Five (3.8%) of 130 gadwalls had ingested shot, and all five contained steel. Out of 86 ringnecks, 3 (3.5%) contained ingested pellets. Two ringnecks had ingested steel and one had ingested lead. Two (3.3%) of 60 lesser scaup contained ingested shot, both with lead. A sample of 148 wood ducks showed one (0.7%) with ingested steel and one (0.7%) with ingested lead. One (0.7%) of 139 pintails contained ingested lead shot, and only one (0.3%) of 366 green-winged teal contained shot. No ingested pellets were found in any of the previous six species collected from either private club (Table 6). Overall, mallards had a higher incidence of ingested shot than expected and pintails, green-winged teal, and wood ducks a lower incidence than expected (chi-square = 36.88, 6 df, $P < 0.005$).

The percentage of ducks with ingested shot at each study site (4.1%, 6.0%, and 8.8% for the MDCWMA, the Boicourt Club, and the Patterson Club, respectively) was significantly different (chi-square = 7.07, 2 df, $P < 0.05$). Of those ducks ingesting some type of shot, the percentage ingesting lead was not the same at all three locations (chi-square = 10.47, 2 df, $P < 0.01$). The incidence of mallard lead shot ingestion (3.2%, 5.6%, and 10.2% at the MDCWMA, the Boicourt Club, and the Patterson Club, respectively) also was significantly different (chi-square = 12.01, 2 df, $P < 0.01$). Mallards harvested at the Patterson Club had more ingested lead and less ingested steel shot than expected. Mallards from the MDCWMA had lower incidences of ingested lead shot than expected, while mallards from the

Boicourt Club showed lead and steel ingested shot incidences close to expected rates.

Rates of mallard shot ingestion rose during each segment of the 3-segment Kansas waterfowl hunting season (Table 10). Mallards at the MDCWMA during the first segment had an ingested shot incidence of 4.8%. This incidence rose to 7.9% and 8.7% during the second and third segments, respectively. The 3-area combined ingested shot incidences were 5.0% for segment I, 8.4% for segment II, and 8.7% for segment III. This seasonal increase in incidence of ingested shot from late October to early January was not significant, however (chi-square = 3.1, 2 df, $P > 0.05$).

Out of 85 gizzards that contained ingested pellets, 64 (75.3%) contained only one pellet. Fourteen (16.5%) contained two pellets, one (1.2%) contained three, two (2.4%) had four, none contained five, one (1.2%) had six, and three (3.5%) had over six pellets inside them (Table 11). The three gizzards that contained greater than six ingested pellets were each collected from the MDCWMA.

Liver Analysis

Fifty-six livers were collected from mallards harvested on the MDCWMA during the 1984-85 waterfowl hunting season. Fifty-four (96.4%) of the livers contained less than 2 ppm lead on a wet weight basis (Table 12). No livers were found with lead levels between 2 and 5 ppm. One liver contained between 6 and 20 ppm lead (10 ppm), and one contained greater than 20 ppm.

Table 10. Number and incidence of ingested shotgun shell pellets (lead and steel) in gizzards of mallards harvested on the three study sites during each of the three Kansas Low Plains hunting season segments.

	Number of gizzards containing shot (%)			
Area	Segment I	Segment II	Segment III	Total (avg)
MDCWMA	10 (4.8)	35 (7.9)	9 (8.7)	54 (7.2)
Boicourt	--[a]	5 (7.0)	--	5 (7.0)
Patterson	1 (7.1)	11 (11.7)	--	12 (11.1)
Total (avg.)	11 (5.0)	51 (8.4)	9 (8.7)	71 (7.6)

[a]No gizzards collected during this time

Table 11. Frequency distribution of number of ingested shot in gizzards of ducks harvested on the three study sites from 1982-1985.

Area	Number of gizzards with shot	Number of shot/gizzard 1		2		3		4		5		6		>6	
		N	%	N	%	N	%	N	%	N	%	N	%	N	%
MDCWMA	68	50	73.5	12	17.6	0	0.0	2	2.9	0	0.0	1	1.5	3	4.4
Boicourt	5	5	100.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Patterson	12	9	75.0	2	22.2	1	11.1	0	0.0	0	0.0	0	0.0	0	0.0
Total	85	64	75.3	14	16.5	1	1.2	2	2.4	0	0.0	1	1.2	3	3.5

Table 12. Number of mallard livers collected falling in each range of lead levels by date of collection at Marais des Cygnes Wildlife Management Area in 1984.

	Lead level (ppm wet weight)			
Date	<2	2-5	6-20	>20
10/20-10/26	9	0	0	0
10/27-11/06	13	0	0	0
11/19-11/27	17	0	0	0
11/28-12/05	2	0	1	1
12/22-12/30	13	0	0	0
Total	54	0	1	1

(30 ppm). Both of the ducks containing elevated lead levels were harvested 1 December 1984.

The gizzard that was collected from the duck with a liver lead level of 30 ppm contained 18 ingested lead shot pellets. The gizzard from the duck that had 10 ppm lead in the liver contained six ingested lead pellets. The gizzard from one duck that had its liver analyzed contained one lead pellet, and gizzards from two ducks that had their liver removed each contained one steel pellet. No other gizzards that came from ducks which had their liver removed contained any shot.

DISCUSSION

Shot in Sediments

It should be emphasized that pellet densities reported in this study would be the maximum expected in small portions of the three study sites. Plots were placed around permanent blinds or locations that had a history of being heavily hunted in order to find the greatest amount of shot possible. Pellet densities on the majority of the plots sampled were well within the range of levels reported in other studies that sampled around "hot spots." Plots on all units on all three study sites except Unit A on the MDCWMA had pellet densities ranging from 0 to 15.50/m^2 (0 to 155,000/ha). Most of the 24 sites that Bellrose (1959) cited contained less than 123,500 pellets/ha. Jessen and Lound (1959) in Minnesota, Anderson (1982b) in Illinois, and Esslinger and Klimstra (1983) in Illinois all reported pellet densities of approximately 100,000/ha in samples taken around blinds, along a firing line, or in other heavily hunted areas. Two studies in which soil samples were randomly collected over a large area also showed pellet densities of approximately 100,000/ha (Schrank and Dollahon 1975, Longcore et al. 1982). It is probable that pellet densities on these last two areas would have been greater than 100,000/ha in specific locations. Pellet densities around specific "hot spots" in Unit A were 23.35/m^2 (233,500/ha) in 1983 and 58.95/m^2 (589,500/ha) in 1984. The latter figure is one of the highest ever reported in the literature, although a specific site sampled at Oakwood Bottoms Greentree Reservoir in Illinois yielded 438,000 pellets/ha and a Missouri study similar to this one found 493,000 pellets/ha

and 397,000 pellets/ha around permanent blinds (Hansen 1976, Humburg and Babcock 1982).

A combination of factors all interact to produce the various pellet densities found. The first two are the soil type and the amount of annual organic matter deposition in the marshes. It is probable that the heavy clay content of the soil is not allowing shot to rapidly settle deeper than 10-12 cm, and that the rate of organic matter buildup is low. More lead shot was found in MDCWMA Unit a than steel four years after lead shot was banned for waterfowl hunting on the MDCWMA. The other interacting factors include past hunting pressure, age of each unit, the cultivation, flooding, and dewatering history of each unit, and the permanency of blinds.

The plots on MDCWMA Unit A were expected to yield the highest density of shot, although the actual density was surprising. Unit A was opened to public hunting in 1968, making it the MDCWMA unit used the longest at 15 years. Although there are no permanent hunting blinds on the MDCWMA, temporary blind placement and favorite hunting locations may be the most important factors involved with high pellet densities on these plots. Unit A is large, however, much of it is deep open water where very little hunting occurs. A small portion of the east side of Unit A normally contains the best feeding areas for dabbling ducks. Hunters crowd into this small area year after year (R.A. Warhurst, pers. commun.). This is the spot where the three soil sampling plots were established. The greatest average annual number of ducks harvested on the MDCWMA come from this unit. Therefore, it has the greatest number of pellets deposited/ha of any unit on the MDCWMA, with most of those pellets falling

into the small area that was just discussed. If 1,000 of the 1,250 ducks harvested on Unit A are killed in the area of approximately 40 ha, then approximately 29,500 pellets would be deposited annually. Total pellet deposition would be 442,500 pellets/ha after 15 years of hunting. The pellet densities found in the plots from Unit A in this study are in the range of the densities that would be expected, considering the figures used to calculate the expected deposition are approximates. This is more support for the statement that the clay content of the soil and/or a low organic matter deposition rate have keep pellets in the upper 10-12 cm of soil. Unit A has never been cultivated, so pellets are not buried in this manner. It is flooded and dewatered quite regularly, making the bottom very firm and not allowing pellets to sink in a soft muck that would form if the sediment was continuously flooded.

MDCWMA Unit F2 yields the lowest harvest of ducks per hectare of any unit sampled, yet of the units sampled it was second in size only to Unit A. Unit F2 has never been cultivated. Hunting tends to be more uniform over the entire unit, and therefore, it is reasonable to have a low average pellet density of zero to 38,500/ha on the two plots. An average annual harvest of 268 ducks in Unit F2 results in an annual deposition of approximately 1,600 pellets/ha. After 10 years of hunting the total deposition should be approximately 10,000/ha, which is in the range found in this study for Unit F2. Unit C2 is hunted fairly heavily, averaging 4-6 ducks harvested/ha, and has never been cultivated. The low average pellet densities of the two plots (38,500/ha in 1983; 33,000/ha in 1984) are probably due to two factors. Hunting is very uniform over the whole unit

so the number of shot/ha would not show a build up in any one location. The second factor is that Unit C2 has only been hunted since 1979. An average annual harvest of 345 ducks in Unit C2 results in an annual pellet deposition of 5,500/hs. The total deposition of pellets after 5 years of hunting should be approximately 27,500/ha. This is within the range of pellets found in the Unit C2 plots in this study.

The average pellet density of the two MDCWMA Unit F1 plots was somewhat higher than that of Units F2 and C2, being 82,000/ha in 1984. Unit F1 is the smallest of the MDCWMA units sampled, yet almost as many ducks are harvested annually from it as from Unit F2. The average harvest/ha is second only to that of Unit A. The hunting is more widespread than on Unit A and not as uniform as Unit C2. Unit F1 had been hunted for 9 years prior to soil sampling, which would make it between Units A and C2 in length of time available for pellet deposition. The total pellet deposition in Unit F1 should be approximately 69,000/ha based on an average annual duck harvest of 227. The 82,000 pellets/ha found on the two Unit F1 plots in this study is very similar to the 69,000/ha expected.

Both the South Feed Lake and East Feed Lake Unit plots on the Boicourt Club yielded 155,000 pellets/ha in 1983 and 131,000 pellets/ha in 1984. The 24,000 pellet/ha difference probably does not reflect a decrease in available shot between years, but rather, the precision of the sampling method. The average duck harvest/ha and number of pellets deposited/ha in the SFL and EFL Units are as high or higher than any unit on the MDCWMA. The marshes at Boicourt have been hunted for at least 75 years. The final factor producing these moderately high shot densities

is that sampling plots were placed around permanent hunting blinds which have been in place for 10-15 years. Estimating the total pellet deposition that would be expected on the units of the Boicourt Club is more difficult than estimating expected pellet deposition on the MDCWMA. Duck harvest records that were obtained went back only 20 years. That leaves 55 years of hunting unaccounted for. Pellet deposition for the past 20 years should be approximately 150,000/ha for the SFL Unit and 110,000/ha for the EFL Unit. Extrapolating these deposition figures out to 75 years results in estimates of 562,500 pellets/ha and 412,500 pellets/ha for the SFL and EFL Units, respectively. Working against a buildup of pellets in the soil is the fact that the EFL Unit had been plowed in 1982, and the SFL Unit was disked three times in 1981. These practices may have buried some of the shot present below the 10-12 cm sampling depth. Frederickson et al. (1977) sampled an area in Missouri before and after cultivation and found shot densities of 303,500/ha and 64,500/ha, respectively. Cultivation may only continue to bury pellets after a few times, however, Eventually it may serve to bring old pellets back up to the surface. It is probable that old pellets have both settled deep and been buried by newer organic matter deposits during the 75 years of hunting at the Boicourt Club. This would result in a lower number of pellets/ha today than what would be expected based on total pellet deposition.

The Smartweed Unit on the Patterson Club had 155,000 pellets/ha in 1983 and 131,000 pellets/ha in 1984. Again I believe this was due to the sampling methods used and does not represent an actual loss of 24,000 pellets. This unit is 11 ha in size and annually yields the most ducks harvested of any Patterson Club

unit. The number of pellets deposited/ha is twice as high as any unit previously discussed. The Smartweed Unit has been hunted for 30 years. Soil samples were collected around a permanent blind that has been in place for 7 years. Estimated total pellet deposition after 30 years is 450,000 pellets/ha. There are two probable reasons for the difference between pellet density expected and that found. First is that this unit was disked to approximately 15 cm in depth in early 1983. The second reason is that enough time has passed since hunting first took place to allow some pellets to both settle deeper and be covered by organic matter deposits.

The plot on the Patterson Club's McKee Unit had half the density of pellets as the plot on the Smartweed Unit. This seems implausible since total pellet deposition is estimated to be 78,000 pellets/ha. The McKee Unit is only 4.5 ha in size, yet almost as manyducks are harvested annually from it as are from the Smartweed Unit. The reason for this moderately low shot density may be related to cultivation on the McKee Unit. The McKee Unit has been disked to a depth of 15 cm and/or plowed to a depth of 23 cm three of the five years previous to soil sampling. It is possible that cultivation did indeed bury many pellets in this instance.

Anderson (1983) suggests that a densityof 50,000 pellets/ha over a large area is the threshold where lead poisoning problems start. Small portions of MDCWMA Units A and F1 and of all four private club units would be potential lead poisoning problem areas based on the 50,000/ha threshold level. It should be reemphasized that worst-case areas were sampled. Only these

smaller parts of the various marshes would be problem areas, not whole marshes. These small areas potentially could pose substantial lead poisoning problems because the most heavily hunted areas also tend to be the areas most utilized by waterfowl.

No steel pellets were found in any soil sample collected from either private club. The private clubs were not required to use steel shot so it would not be expected that anyone hunting there would. However, the data from the MDCWMA are surprising. Seventy-two percent of the pellets found from the MDCWMA were lead, with the widest disparity of number of lead: steel occurring in 1984. Steel shot has been required for 12 gauge guns at the MDCWMA for four years previous to this study, and three years previous for all gauges. Either the lead shot deposited before 1979 has remained in the top 10-12 cm or there have been many persons using lead shot illegally. The results are most likely a combination of the two, however, the major factors are probably slow pellet settling rates and/or a low rate of organic matter deposition. This can be seen from the soil sampling results from Units A and F2 on the MDCWMA which show that the number of pellets/ha found is close to the number of pellets/ha expected after 10-15 years of hunting. Results from the two private clubs seem to indicate that it takes approximately 25-30 years to show any appreciable natural reduction in density of pellets in the top 10-12 cm of the clay soil type found in this area. Assuming nobody shot lead illegally it may be 40-50 years before the present amount of lead shot will be below the top 10-12 cm.

Artifically Seeded Shot

Even though there was no statistical loss of pellets out of the top 10-12 cm of substrate during one year on Unit F1, the shot may not have been in the surface layer. No attempt was made to divide the soil cores into layers for analysis. Much of the shot could conceivably have been 10 cm deep and not as readily available to feeding waterfowl. This does not seem probable however. If shot were to settle or be buried deeper than 8 cm in one year then the same rate should hold true for pellets in the other MDCWMA units. However no evidence was found to support a rapid settling of pellets or a rapid buildup of organic matter.

Wycoff et al. (1964) artifically seeded pellets in Catahoula Lake, LA, and found that lead shot seeded in the Lake remained readily available to waterfowl after two years. The Lake had a silty loam to a silty clay loam bottom, with a clay layer at variable depths. Bellrose (1959) seeded pellets inside ceramic pipes that were sunk into a moderately firm-bottomed lake bed. Five 2.5 cm layers were removed from the pipes one year later and screened for shot. He found that the bulk of the shot was in the top 2.5 cm layer.

The regularity that Unit F1 is drained also plays a role in pellet settling rates. Approximately every other year Unit F1 is drained, which keeps the bottom very firm. Areas that are continuously flooded tend to develop very soft bottoms where pellet settling rates would be expected to be much faster.

One problem with the soil sampling design was the number of soil cores collected on each plot. Many more samples would have to be collected from each plot to have more confidence in the pellet density data. Finding one pellet in a plot of 75 core

samples in 1984 extrapolated to 65,500 pellets/ha. Five-hundred samples/plot would need to be collected with the core sampler used in this study for one pellet to extrapolate to 10,000 pellets/ha.

Comparison of Soil Core Analysis Methods

Radiographic (x-ray) methods combined with manual verification detected more pellets present in soil cores than found by manually sieving the cores and visually searching for pellets. More than twice as many pellets were found with x-rays than with the sieve screen (7 vs. 3) in the four plots that were analyzed using both methods. It is easy to miss a small lead pellet while searching through the debris left after marsh sediment has been sieved. Pellets may appear to be stones or become hidden in a tangle of vegetation. Becuase very often few pellets are found, the searching becomes tedious and a person may become fatigued and careless. This would allow pellets to go unnoticed. X-rays allow quick analysis of many samples and reduces the fatigue problem. Pellets also appear clearly on the x-ray plate even in the presence of much other debris. Samples that contain no shot can be quickly discarded, and only those samples showing pellet-like signatures on the x-ray can be searched carefully.

The costs of the two methods are comparable if equipment is available. Ten soil samples can be sieved and searches for shot in 1 hour, i.e., a cost of \$450.00 per 1,000 samples assuming a \$4.50 per hour wage scale. Approximately 100 samples can be prepared for x-raying in an hour (45.00 per 1,000, assuming a \$4.50 per hour wage scale). Twenty-five core samples fit on one

sheet of x-ray film and each sheet of film cost \$10.00 (\$400.00 film costs per 1,000 samples). Manually searching an estimated 10% (100) of the x-rayed samples results in an additional \$45.00 expense. The total cost per 1,000 samples x-rayed would then be \$490.00, only \$40.00 more than searching the samples manually. The cost differential is not that great considering the increased accuracy obtained with x-rays.

Ingested Shot in Gizzards

Mallards harvested at all three study areas had incidences of ingested shot greater than 5% over 3 years. The high mallard ingested shot incidence of 10.0% at the MDCWMA in 1984-85 and the doubling of the rate of ingested lead shot by mallards in 1984-85 cannot be readily explained. Contrastingly, pintails collected at the MDCWMA had a 3-year ingested shot incidence below 1%. This 1% rate is lower than almost all other samples of pintails taken around the country (Reid 1948, Bellrose 1959, Carson 1974, White and Stendell 1977, Baker and Thompson 1980, Browne 1981, Longcore et al. 1982). Pintails generally feed in the same habitat and in the same manner as mallards, so the reason they did not pick up more pellets is not readily apparent. The green-winged teal and wood duck incidences of ingested shot of less than 1.5% are most likely due to the feeding habits of these species. Teal feed on the surface of the mud bottom and wood ducks on fruits in flooded woodlands. These feeding niches often do not expose teal or wood ducks to shot in sediments. Lesser scaup and ringnecks harvested on Marais des Cygnes had shot ingestion rates similar to each other, although ringnecks ingested mostly steel shot while scaup ingested lead shot exclusively.

A possible reason for this difference in type of ingested shot between these two similarly-feeding species is an inadequate sample size of each species. Only 86 ringnecks and 60 lesser scaup were sampled in 3 years. In fact the difference in number of each shot type ingested by each species is not significant (chi-square = 0.09, 1 df, $P > 0.05$). Gadwalls ingested only steel shot at an intermediate rate over 3 years, but had an ingested shot incidence of 15.4% in 1983-84. This 15.4% incidence was based on a sample of 13 gizzards. Because of the small sample size the 15.4% incidence found in 1983-84 is not significantly different from the 5.6% incidence found in 1982-83 that was based on 54 samples (chi-square = 1.46, 1 df, $P > 0.05$). The ingested shot incidences of the seven species sampled at the MDCWMA generally fell in the relative order that other authors have reported with the exception of pintails (Bellrose, 1959, Longcore et al. 1982, Moser and Keeler 1982).

Only mallards yielded a large enough sample from the Boicourt Club to give any meaningful data. Mallards ingested lead shot at a rate four times greater than steel shot at Boicourt. This probably is a reflection of the fact that only lead shot was found in the soil samples from Boicourt.

The mallard was also the only species at the Patterson Club to yield an adequate sample. The 11.1% incidence of shot in gizzards of mallards harvested on the Patterson Club was higher than that of mallards from either other location. The two Patterson Club units on which most of the harvest occurs on are small (4.5 and 11.3 ha), and these units are also the ones with the best feeding areas on the Club. Ths small unit sizes would tend to concentrate ducks feeding in those units. This would

increase the probability of a duck ingesting a pellet, especially if a flock was concentrated in front of a permanent hunting blind. Eleven mallard gizzards contained ingested lead shot whereas only one mallard gizzard contained an ingested steel pellet at Patterson. The differential may be a reflection of the fact that only lead shot was found in soil samples from the Patterson Club.

The incidence of shot in gizzards of all ducks collected during this 3-year study was 4.5%. This incidence is higher than the 3.1% incidence of ingested shot that Bellrose (1959) reported as the average figure for the Central Flyway. Thousands more pellets have been deposited in the nation's wetlands since 1959, and incidences of ingested shot would be expected to rise. Also individual locations would not be expected to show ingested shot incidences that are the same as average incidences for a very broad geographical area.

Current guidelines used by the U.S. Department of the Interior state that hunting areas where the duck harvest is greater than 10 ducks/sq. mi. and 3-year incidences of ingested shot of certain indicator species are greater than 5% should be proposed to be nontoxic shot zones. The three study sites all harvest greater than 10 ducks/sq. mi. The recommended sample size for monitoring ingested shot incidences is 100 gizzards of a certain species. Acceptable indicator species include mallards and pintails.

Mallards harvested at all three study areas had 3-year ingested shot incidences greater than 5%. Mallard sample size was 754 at the MDCWMA, 72 at Boicourt, and 108 at Patterson.

Under federal guidelines the MDCWMA and the Patterson Club should be considered for inclusion in a steel shot zone. With collection of additional samples from the Boicourt Club, it most likely would be included in the steel shot zone also. Marais des Cygnes has been a steel shot area since 1980 and would not be affected by the guidelines.

Higher percentages of mallards were found with ingested shot during the last two segments of the Kansas waterfowl season than in the first segment, however the difference was not significant. Bellrose (1959) and Anderson and Brewer (1980) each reported significant increases in ingested shot incidences as the season progressed. Welch (1976) found that incidences of ingested shot of mallards from certain locations in Illinois rose slightly but not significantly as the hunting season progressed. It seems that changes in incidences of ingested shot with hunting season progression are variable from location to location and do not always rise as it gets later in the year.

Sixty-four of the 85 ducks (75.3%) found with ingested pellets had only one pellet in their gizzard. An additional 14 (16.5%) contained only two pellets. This is encouraging because one or two pellets are usually not fatal to a duck depending primarily upon the diet of that duck at the time. Ducks that ingest 1-2 lead pellets that are on an exclusively corn diet have mortality rates of 35-100% (Irby et al. 1967, Locke et al. 1967, Longcore et al. 1974b, and Finley and Dieter 1978). As other diet constituents replace corn in the diet the mortality rate decreases. Finley et al. (1967a) observed no mortality in mallards dosed with on No. 4 lead shot and fed one-half yellow corn and one-half commercial breeder pellets. Even mallards

dosed with six No. 6 lead pellets only incurred a 40% mortality rate when they were fed a diet of mixed cereal grains (Barrett and Karstad 1971). Bellrose (1959) banded over 3,500 mallards and dosed them with zero (controls), one, two, four, or six lead pellets. Band recoveries were tabulated for the first 4 years after banding and mortality rates between populations with each dose calculated. It was found that one No. 6 lead pellet per bird produced a 9% increase in the mortality rate; two pellets 23%; four pellets 36%; and six pellets 50% (Bellrose, 1959). Four gizzards (4.7%) were found with six or more ingested pellets in my study, which may have resulted in the death due to lead poisoning of two of them if they had not been killed by hunters.

Erosion and elimination of shot from a duck's digestive system is governed by many factors. However in most cases shot voidance is fairly rapid. Over 92% of the surviving ducks dosed with eight pellets had eliminated all of the pellets in 4 weeks (Krystofik 1985). Most ducks that succumb to lead poisoning usually die within 2 to 3 weeks after shot ingestion (Jordon and Bellrose, 1950, Godin 1967, Irby et al. 1967, Locke et al. 1967, Bates et al. 1968, Grandy et al. 1968). Bellrose (1959:281) states that "observations in the field and in the laboratory indicate that a mallard that survives ingestion of lead will have eliminated the lead 18 days, on the average, after ingestion."

The method originally developed by Bellrose (1959:280) and subsequently used by Welch (1976), Anderson and Brewer (1980), and Trost (1980) allows an estimate to be made of the proportion of the mallard population at Marais des Cygnes that could succumb annually as a result of lead poisoning. The same approach allows

an estimation of the proportion of mallards annually saved from death due to lead poisoning because of the use of steel shot at MDCWMA.

Ingestion of a lead shotgun pellet by a duck was found to increase male mallard vulnerability to hunting (Bellrose 1959). Mallards with one lead pellet in their gizzard are 1.5 times as likely to be killed as ducks without lead in their gizzard, those with two pellets are 1.9 times more vulnerable, and those with four pellets 2.1 times as likely to be killed than those without lead shot. Hunting bias figures for birds with three, five, six, and greater than six shot were derived from interpolation or extrapolation of the available data.

Earlier in this Discussion section it was stated that 18-21 days after shot ingestion is the average time that a duck either succumbs to lead poisoning or voids the shot. With this in mind, 20 days was selected as the average turnover of ingested pellets.

The number of mallards ingesting shot in a Kansas 60-day hunting season would be three times the average number obtained from samples during the hunting season if gizzards collected at any one time represent only a 20-day turnover period. Therefore, a factor of three was used in correcting ingested shot incidence for turnover.

Table 13 presents the expected mortality of mallards from all three study sites that were found to have ingested only lead shot. An estimated 1.07% of the mallard population using the Marais des Cygnes Wildlife Management Area, Boicourt Shooting Club, and Patterson Duck Club may have succumed to lead poisoning annually from 1982 to 1985. Bellrose (1959) calculated a 3.98% lead poisoning mortality of mallards nationwide, Welch (1976)

Table 13. Estimated mortality of mallards due to lead poisoning using only those mallards ingesting lead shot. Data derived from examination of mallard gizzards collected at the three study sites from 1982-1985.[a]

Shot/gizzard	% Ingested shot incidence (N) A	Hunting bias correction factor[b] B	Incidence corrected for hunting bias A/B	Incidence corrected for turnover A/B x 3	Mortality rate (%)[b] C	Estimated mortality (%) (A/B x 3) x C
1	3.2 (30)	1.5	2.13	6.39	9	0.58
2	0.4 (4)	1.9	0.21	0.63	23	0.15
3	0.1 (1)	2.0	0.05	0.15	30	0.05
4	0.1 (1)	2.1	0.05	0.15	36	0.05
5	0.0 (0)	-	-	-	-	-
6	0.1 (1)	2.3	0.04	0.12	50	0.06
>6	0.2 (2)	2.4	0.08	0.24	75	0.18
Total	4.8 (39)		3.01			1.07

[a]Table is modeled after that of Bellrose (1959:280)

[b]From Bellrose (1959:280)

a 0.95% mortality of mallards in Illinois due to lead poisoning and Trost (1980) a 2.28% mallard mortality due to lead shot ingestion on the Upper Mississippi National Wildlife Refuge employing the same method utilized here in this study. If steel shot had not been mandatory at the MDCWMA and all pellets ingested by mallards were assumed to be lead, then an estimated 2.03% of the mallard population using these complexes of wetlands would have died of lead poisoning (Table 14). The difference, 0.96% is the estimated percentage of the mallard population saved from death due to lead poisoning. An estimate of the number of ducks spared from death by lead poisoning can be obtained by using fall waterfowl census data for Marais des Cygnes. The average fall peak number of mallards using the MDCWMA at any one time during the past 4 years was 51,000 (R.A. Warhurst, unpubl. reps.). This is not the total number of mallards that use the MDCWMA during the entire fall but only the peak number using the MDCWMA during a single week. An estimated total of 546 mallards would die from lead poisoning based on the 1.07% mortality rate calculated. An estimated 1,035 mallards would have died if all shot ingested was lead shot. The mandatory use of steel shot at the MDCWMA may have saved an estimated minimum of 489 mallards from death due to lead poisoning. This figure is a minimum because (1) the peak number of mallards on the MDCWMA during one week of the fall was used instead of taking turnover in the mallard population into consideration, and (2) only the peak number of mallards using Marais des Cygnes was used because counts were not taken of mallard numbers on the two private clubs. If the total number of mallards that utilize the three study sites from October-January could be accurately determined then the number of lead poisoning

Table 14. Estimated mortality of mallards due to lead poisoning assuming all pellets ingested were lead. Data derived from examination of mallard gizzards collected at the three study sites from 1982-1985.[a]

Shot/gizzard	% Ingested shot incidence (N) A	Hunting bias correction factor[b] B	Incidence corrected for hunting bias A/B	Incidence corrected for turnover A/B x 3	Mortality rate (%)[b] C	Estimated mortality (%) (A/B x 3) x C
1	5.4 (50)	1.5	3.60	10.80	9	0.97
2	1.5 (14)	1.9	0.79	2.37	23	0.55
3	0.1 (1)	2.0	0.05	0.15	30	0.05
4	0.2 (2)	2.1	0.10	0.30	36	0.11
5	0.0 (0)	-	-	-	-	-
6	0.1 (1)	2.3	0.04	0.12	50	0.06
>6	0.3 (3)	2.4	0.13	0.39	75	0.29
Total	7.6 (71)		5.78			2.03

[a]Table is modeled after that of Bellrose (1959:280)

[b]From Bellrose (1959:280)

deaths and the number of ducks saved would be substantially higher. No attempt was made to extrapolate the estimates of mallard mortality to other species of ducks. Data used in Tables 13 and 14 were originally generated using mallards and may not apply to other species. However there would be expected to be some lead poisoning mortality of any duck species that regularly ingested lead shot.

Comparison of Gizzard Analysis Methods

During the first 2 years of this study, gizzard contents from 925 ducks were analyzed for shot by visually examining them. These 925 gizzard contents were re-examined during the third year of the study by x-ray. The results of these separate examinations permitted a comparison of the two analytical methods.

Four more steel pellets and 10 more lead pellets were found with the x-ray method than were found by visually searching gizzard contents. If we assume the x-ray results represent the true results, then four of 23 (17.4%) ingested steel pellets were missed and 10 of 20 (50%) ingested lead pellets were missed by the visual search method. A combined total of 32.6% of the ingested pellets present in gizzards collected during the first two years of this study were not observed by visually examining gizzard contents. Both Montalbano and Hines (1978) and Anderson and Brewer (1980) found that manual examination of gizzard contents may miss up to 25% of the pellets present. Pellets are ground down in the gizzard and become very small, thin, and wafer-like. These pellets are easily missed or mistaken for other gizzard material. Pellets were easily spotted on the x-rays, even the ones that resembled small wafers. All samples that produced a small bright white spot on the x-ray were

manually searched to verify the presence of a pellet. If an x-rayed sample was even questionable that sample was searched. Approximately two to three x-ray images were called "positive" for 25 cores x-rayed when the analyses were first begun. The number of false images called "positive" was reduced to zero or one per 25 with experience. Radiologic examination of gizzard contents followed by manual examination of the contents that produced a positive signature on the radiograph is now considered to be the most accurate method of determining incidences of ingested shot (Montalbano and Hines 1978, Anderson and Brewer 1980, Anderson and Havera 1985).

As with the analysis of soil samples, the costs of analyzing gizzard samples by the two methods are comparable if equipment is available. Twelve to 15 gizzard contents can be manually searched for pellets in 1 hour, i.e., a cost of $300.00 to $375.00 per 1,000 samples assuming a $4.50 per hour wage scale. Approximately 20 gizzards can be opened and prepared for x-raying in an hour ($225.00 per 1,000 assuming a $4.50 per hour wage scale). Each sheet of x-ray film cost $10.00 and 120 vials of gizzard contents fit on one sheet of film ($90.00 film costs per 1,000 samples). Manually searching an estimated 5% (50) of the x-rayed samples results in an additional $9.00 expense. The total cost per 1,000 gizzard contents x-rayed would then be $324.00, which is between $51.00 less and $24.00 more than searching the samples manually.

Liver Lead Analysis

Fifty-four of the 56 mallard livers collected at the MDCWMA contained less than the 2 ppm lead wet weight level of detection.

One liver contained 10 ppm lead (wet weight) and another contained 30 ppm lead (wet weight). Longcore et al. (1974) states that waterfowl livers containing greater than 6 ppm lead (wet weight) are indicitive of recent, acute lead toxicosis. This suggests that 3.6% of the mallards that had livers taken from them were suffering from lead poisoning. The 3.6% lead poisoning rate seems too high to extrapolate it to the Marais des Cygnes mallard population as a whole. The mallard sample that these livers were collected from may unknowingly not have been a representative sample. The incidence of ingested lead shot found in the gizzards corresponding to the 56 livers was 5.4%. This ingested lead shot incidence is 50% greater than the 3.2% incidence of ingested lead shot found in the 754 mallard gizzards collected at the MDCWMA over 3 years. Therefore the amount of lead in the mallard sample that had livers removed may not have been representative of the lead burden of the total mallard samples collected.

Gizzards from three ducks that had their liver removed contained ingested lead shot. However only two of these three ducks would be considered lead poisoned as evidenced by liver lead levels. This illustrates the point that gizzard ingestion data alone are not sufficient to indicate that there is a lead poisoning problem among a population of ducks. Incidence of lead shot in gizzards indicates a potential for a lead poisoning problem, but only analyses of lead concentration in body tissues will substantiate toxic levels of lead sufficient to cause mortality.

The colorimetric dithizone test used to analyze the livers in this study is a simple diagnostic test used to estimate lead concentrations. The lower limit of detection is 2 ppm wet weight

and has a standard deviation of approximately ±2ppm. It is not sufficiently sensitive to be considered a quantitative analytical procedure (Hammond et al. 1965). Because results were not needed in tenths of a ppm, it was adequate for the needs of this research. Both livers that were found to contain lead were high in lead content (10 and 30 ppm). There was no question about the amount of lead present in these two samples. Because the resulting color of the remaining 54 liver samples matched the color of the blank there was no question that they contained less than 2 ppm lead.

Integration of Soil and Gizzard Results

A point was made at the beginning of the Study Areas section that the ducks using the 3-area complex of wetlands should be considered as one population because of the close proximity of the three areas to each other. If this is indeed true, then why do ducks harvested at both private clubs contain a greater percentage of ingested lead shot than steel, while those ducks harvested at the MDCWMA show lead vs. steel ingested shot incidences approximately equal? There are three possible explanations. The first is that the sample size from the two private clubs was not large enough and more ducks with ingested steel shot than lead shot may have been found with a larger sample. While this may be true, I believe it is not. The fact that 11 times the number of lead shot as compared to steel shot were found ingested in a sample of 136 ducks from the Patterson Club leads me to believe that more lead shot than steel would normally be found ingested in ducks harvested on the private clubs.

The second explanation is that there are three distinct and separate populations of ducks using the three study sites for feeding and resting. Flocks of ducks may establish favorable feeding sites and may continue to use them until they either migrate out of the area, are killed by hunters, or find a better site. Therefore, if a flock of ducks is using one of the three areas for feeding, they may use that same area for a period of time and will show shot ingestion patterns based on shot availability in the marshes of that particular area. The data from this study could possibly be used to support this argument. Only lead shot was discovered in the soil plots on the two private clubs, and mostly lead shot was found ingested by ducks harvested on the clubs. Both lead and steel shot were found on the soil plots at the MDCWMA, and both types of shot were found ingested by ducks harvested at the MDCWMA. There are two reasons why this three separate population-theory probably is not correct. First is that a small percentage of ducks harvested from each private club contained ingested steel shot. If no steel shot was present in the private club marshes and flocks remained faithful to their respective feeding sites, from where did the ingested steel shot come? The second is the reasoning behind the original statement that there is only one duck population using the entire wetland complex. The total width and length of the three-study-site area is 6.4 km and 9.7 km, respectively. These distances are well within the reported daily flight range of ducks (Parr et al. 1979, Baldassare and Bolen 1984). It would seem probable that various flocks of ducks are constantly intermingling, especially with hunters harassing them.

The third explanation for the disparity in types of ingested shot is probably the most easily supported. The basic premise behind this theory is that ducks with ingested lead shot do not fly around and interchange among marshes as much as non-lead carrying ducks. There is very little data on this, but it would seem to be plausible. Bellrose (1959) found that ingestion of lead shotgun pellets greatly retarded migration. He banded and dosed 1,200 ducks with various levels of lead shot and plotted recovery location vs. dosage level. It was found that the greater the number of lead pellets a duck had ingested the less far that bird traveled. Bellrose (1959:273) stated that "the weakness and fatigue associated with lead poisoning reduces the movement of ducks." The gizzard data may then be correlated with the soil data based on this reduction in movement. A small percentage of ducks harvested at the two clubs contained ingested steel shot. The steel probably was picked up in marshes on the MDCWMA and the duck subsequently flew onto club property at a later time and was killed. Because the soil in the marshes on the private clubs contained only lead shot, any pellet ingested on private club marshes would be lead. After ingestion of a lead shot pellet the individual may become more sedentary and remain for a longer time in that marsh. That individual duck would probably then be more vulnerable to hunting. The resulting shot ingestion data from the private clubs should then show a greater percentage of ducks with ingested lead than steel. This was indeed what my data showed (Table 6). Because 21 out of the 29 pellets (72.4%) found on plots located on MDCWMA units were lead, a question may arise as to why more steel shot than lead shot was found ingested by ducks harvested on the MDCWMA (Table 6). It was postulated earlier in

the Discussion that the heavy clay content of the soils in the area and/or a low rate of organic matter deposition may be preventing pellets from being deeper in the substrate. Lead pellets are still available to waterfowl after 4 years of a lead shot ban as evidenced by both soil and gizzard results. This lead shot reservoir may be several cm deep however. A layer of steel shot may lay on top of the lead from 4 years worth of using steel for hunting. This scenario would allow both lead and steel shot to be ingested, but because steel shot is in the uppermost layer, steel would probably be ingested slightly more frequently.

The above explanation could be used to support the hypothesis that ducks predominantly ingest shot from the area on which they are harvested and may show shot ingestion patterns that can be explained by pellet availability in local marshes. Some shot is undoubtedly ingested before ducks reach the MDCWMA. However incidences of shot ingestion between the MDCWMA and the private clubs should be similar if the majority of shot is ingested elsewhere. To my knowledge there has not been a similar study to this one comparing incidences of ingested shot with soil availability of pellets between areas that require steel shot and those that use lead for waterfowl hunting. In summary it can simply be stated that non-lead carrying ducks interchange freely among the marshes in the area, while those ducks with ingested lead become fairly sedentary on the marshes where they ingested the lead.

Management and Research Recommendations

There are two solutions to completely halt waterfowl deaths due to lead poisoning by ingestion of spent lead shotgun pellets.

One is to stop hunting and the other is to ban use of lead shot. I do not consider the stopping of hunting to be a viable or reasonable solution. A ban on lead shot, however, is reasonable and attainable. Lead shot can be available to waterfowl years after its use has been halted as seen at the MDCWMA. Other methods must be employed to make this reservoir of lead shot less available until the time comes when it has reached unavailable depths. This length of time may be 40-50 years in the case of Marais des Cygnes. Methods such as deep flooding or draining a marsh will not reduce the amount of shot but will make it less available. However these methods also make the area less attractive to feeding waterfowl and hunters. Deep flooding or draining may be methods to reduce ingestion of shot by waterfowl in the spring months when it is also probable that ducks ingest pellets. Cultivation can reduce pellet availability in some cases. Small "hot spot" areas could be targeted for cultivation during the summer when units are drawn down. This could be a short term solution to lessen pellet availability. The potential danger with cultivating on the MDCWMA would be that more lead pellets would be brought to the surface than would be buried. A small area should be sampled first, cultivated, then sampled again to find out if this would occur. Besides draining or deep flooding the marshes for 10-20 years or intermittantly scaring ducks off an area, these are the only practical methods of making pellets less available to feeding waterfowl.

Another alternative is to do nothing except continue to use steel shot and let the old lead shot settle and/or be buried naturally. This is where future research could come in.

Mallard gizzards and livers should be analyzed every year from ducks harvested on the MDCWMA and checked for ingested shot and lead content, respectively. A sample of 100-200 mallard gizzards and livers annually would be adequate. Gizzard examination would detect changes in ingestion rates of lead shot and would document when methods to make shot less available could be discontinued.

Summary and Conclusions

A 3-year research project was initiated in the fall of 1982 to determine incidence of ingested shot in seven species of ducks, pellet availability in marsh sediment, and the effectiveness of a non-toxic shot regulation. This study was conducted in eastern Kansas on the Marais des Cygnes Wildlife Management Area (MDCWMA) and two private duck hunting clubs in the vicinity. A total of 1,902 gizzards were collected from hunter-killed ducks from the three study sites over 3 years. Ducks harvested at the MDCWMA had incidences of ingested lead shot of 1.8% and 2.3% for steel shot. Ingested shot incidences were 4.8% for lead and 1.2% for steel for ducks harvested at the Boicourt Club. These shot incidences were 8.1% for lead and 0.7% for steel at the Patterson Club. Pellet density in marsh sediments ranged from 0-589,500/ha with the greatest density occurring on the MDCWMA. Both lead and steel shot were found in MDCWMA marshes, while only lead shot was found in sediments on the two private clubs. It was estimated that a minimum of 489 mallards using the MDCWMA were saved from death due to lead poisoning because the steel shot zone at the MDCWMA.

The following conclusions can be drawn from this study:

1. Most of the marshes sampled had moderate densities of pellets in the sediments, however pellet densities were very high in small specific locations on MDCWMA Unit A. Potential lead poisoning problem areas exist on MDCWMA Unit A and F1 and on all four private club units studied. The problem areas are very small compared to overall marsh area but these small areas probably support the greatest duck use.

2. Radiographic (x-ray) methods of gizzard content and soil analysis combined with manual verification detected more pellets than found by visually searching gizzard contents and soil cores.

3. The cost of gizzard content analysis and soil core analysis by x-ray is comparable to the cost of manual analysis of gizzard contents and soil cores if x-ray equipment is available.

4. Ducks probably predominantly ingest shot from the area on which they are harvested, and the number and type of ingested shot reflects the pellet availability in local marshes.

5. Non-lead carrying ducks may interchange freely among the marshes in the area, while those ducks with ingested lead may become fairly sedentary on the marshes where they ingested the lead.

6. An estimated minimum of 546 mallards using the MDCWMA die annually as a result of lead poisoning, while the mandatory use of steel shot at the MDCWMA saves an estimated minimum of 489 mallards annually from death due to lead poisoning.

7. Cultivation, deep flooding, or draining portions or all of certain marshes are the only methods of reducing availability of pellets to feeding waterfowl until the reservoir of lead

pellets becomes unavailable by natural organic matter deposition and/or pellet settling. These natural processes may take 40-50 years to make the lead shot reservoir unavailable.

8. The whole complex of wetlands in the vicinity of the Marais des Cygnes Wildlife Management Area should be considered for inclusion in a non-toxic shot zone under current federal guidelines.

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Appendix A. Procedure for the colorimetric lead test used in this study to determine levels of lead in duck livers.

NOTE: Absolutely clean, lead-free glassware must be used for this test.

For each liver do duplicate samples, which means using two wide-necked (wide) and two narrow-necked (narrow) test tubes (tt) for each liver.

Run one blank and one standard for each group of livers analyzed.

A. Specimen Preparation

1. Homogenize each liver (Kinematica GmbH PCU-2-110 polytron homogenizer). Rinse off homogenizer blades with distilled water after each liver.
2. Weigh out 0.50 g of each homogenized sample and place into wide tt.
3. Add 10 ml of 5% lead-free trichloroacetic acid (5% tca) to each sample tt, cover the sample tt with paraffin and vortex the samples.
4. Allow the sample tt to stand for 1-2 hours.
5. Centrifuge the sample tt at 1,350 g's of force (2,500 rpm's) for 10 minutes, then pour the supernatant into narrow tt.
6. Add another 10 ml 5% TCA to the wide tt, re-centrifuge the wide tt as in step 5, and add the supernatant to that obtained in step 5.

B. Color Development

1. Add 20 ml 5% TCA to the blank tt, and 15 ml 5% TCA to the standard tt.
2. Add 5 ml of lead standard to the standard tt.
3. Add 10 ml alkaline reagant to all sample narrow tt, and the blank and standard tt.
4. Add 10 ml dithizone solution to all sample narrow tt, and the blank and standard tt.
5. Stopper the narrow tt and mix the solutions by gently inverting the tt, and allow for the color to develop (3-5 min). Read the results by comparing the narrow tt to a lead concentration in liver color chart.

Appendix B. Directions for preparation of solutions required in the colorimatic lead test.

A. Dithizone (Diphenylthiocarbazone)

1. Dissolve 40 mg dithizone in 500 ml chloroform (Solution a).

2. Take 50 ml of solution a and add 450 ml chloroform.

3. Protect from light and store in the refridgerator.

B. Alkaline reagent - liter

1. Fill a 1 liter beaker with deionized water and place on a hot plate.

2. Weigh out:
150 g Sodium carbonate (anhydrous)
100 g Sodium citrate
20 g Potassium cyanide
20 g Sodium hydroxide

3. Pour the hot water into a 1 liter flask, add the chemicals, and use a stir bar to mix the solution.

4. Let the solution cool 12-24 hours in the dark.

5. Store at room temperature protected from light.

C. 5% lead-free Trichloroacetic Acid (TCA)

1. Dissolve 50 g Trichloroacetic acid in 1 liter of deionized water.

2. Pour this solution into a 1 liter brown bottle which contains 100 g of Amberlite IR 120(H) (16-50 mesh) ion exchange resin.

3. Let the solution and beads set 2-3 days or until a blank is tested and the resulting color shows no lead present. Mix the solution and beads by inverting the bottle twice a day.

4. Protect the finished product from light and store in a refridgerator, and store the beads under deionized water.

D. Lead standard

1. Dissolve 0.165 g of dried (110° overnight) lead nitrate in 990 ml distilled water plus 10 ml of concentrated

nitric acid (call this the stock solution).

2. Add 1 ml of the stock solution to 99 ml of 5% lead-free TCA and the result is the 0.01% lead standard.

Appendix C. Names and addresses of companies from where chemicals used in the colorimetric lead test were obtained.

Chemical	Company
Diphenylthiocarbazone (Dithizone)	Fisher Scientific Company Fair Lawn, NJ 07410
Rexyn 101 (H)	"
Chloroform	"
Amberlite IR 120(H)	Eastman Kodak Company Rochester, NY
Sodium hydroxide	J.T. Baker Chemical Company Phillipsburg, NJ 08865
Potassium cyanide	"
Trichloroacetic acid	EM Science Gibbstown, NJ 08027
Sodium citrate	"
Sodium carbonate	Taylor Chemical Company St. Louis, MO 63144

THE INCIDENCE AND AVAILABILITY OF LEAD AND STEEL
SHOTGUN PELLETS IN DUCKS AND MARSHES IN EASTERN KANSAS

by

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B. S., Michigan State University, 1983

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Division of Biology

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1986

ABSTRACT

Lead poisoning, caused by the ingestion of lead shotgun pellets, is one of the many mortality factors of wild waterfowl. A 3-year research project was initiated in the fall of 1982 to determine incidence of ingested shot in seven species of ducks, pellet availability in marsh sediment, levels of lead in livers of mallards (Anas platyrhynchos), and the effectiveness of a non-toxic shot regulation. This study was conducted in eastern Kansas on the steel shot only Marais des Cygnes Wildlife Management Area (MDCWMA) and two private duck hunting clubs in the vicinity. Gizzard contents and soil cores were analyzed for shot by radiography. Radiographic (x-ray) methods of gizzard content and soil analysis combined with manual verification detected more pellets than found by visually searching gizzard contents and soil cores. A total of 1,902 gizzards were collected from hunter-killed ducks from the three study sites over 3 years. Ducks harvested at the MDCWMA had incidences of ingested lead shot of 1.8% and 2.3% for steel shot. Ingested shot incidences were 4.8% for lead and 1.2% for steel for ducks harvested at the Boicourt Club. These shot incidences were 8.1% for lead and 0.7% for steel at the Patterson Club. Mallards generally showed the highest incidence of ingested shot. Ducks probably predominantly ingest shot from the area on which they are harvested, and the number and type of ingested shot reflects the pellet availability in local marshes. Pellet density in marsh sediments ranged from $0-58.95/m^2$ (0-589,500/ha) with the greatest density occurring on MDCWMA Unit A. Both lead and steel shot

were found in MDCWMA marshes, while only lead shot was found in sediments on the two private clubs. Most of the marshes sampled had moderate densities of pellets in the sediments, however pellet densities were very high in small specific locations on MDCWMA Unit A. Potential lead poisoning problem areas exist on MDCWMA Units A and F1 and on all four private club units studied. The problem areas are very small compared to overall marsh area but these small areas probably support the greatest duck use. An estimated minimum of 546 mallards using the MDCWMA die annually as a result of lead poisoning, while the mandatory use of steel shot at the MDCWMA saves an estimated minimum of 489 mallards annually from death due to lead poisoning. Cultivation, deep flooding, or draining portions or all of certain marshes are the only methods of reducing availability of pellets to feeding waterfowl until the reservoir of lead pellets becomes unavailable by natural organic matter deposition and/or pellet settling. These natural processes may take 40-50 years to make the lead shot reservoir unavailable. The whole complex of wetlands in the vicinity of the Marais des Cygnes Wildlife Management Area should be considered for inclusion in a non-toxic shot zone under current federal guidelines.